Author:
Rees, Sian

Title:
Examining the Impact of Memory and Processing Speed Deficits upon Literacy Attainment in Key Stage 3 Pupils in a UK Mainstream Secondary School

Examining the Impact of Memory and Processing Speed Deficits upon Literacy Attainment in Key Stage 3 Pupils in a UK Mainstream Secondary School

Sian Ellen Rees

A dissertation submitted to the University of Bristol in accordance with the requirements for award of the degree of MSc by Research in the Faculty of Life Sciences, School of Psychological Science. August 2018

Word count: 28,269

Abstract

Memory abilities and processing speed are well researched areas of cognitive function. In previous studies, short term and working memory and processing speed have been identified as predicting factors. Research focusing on the literacy attainment of Key Stage 3 pupils in the UK is less well debated. In this study the current level of support for students with cognitive processing deficits is discussed. KS3 mainstream students were assessed using the Raven standard matrices; using a matched pairs design on the basis of raw scores achieved, 42 participants were allocated to either a lower or higher achieving literacy group determined upon Key Stage 2 SATs results. Participants then performed visual spatial and verbal short-term and working memory, alphanumeric rapid naming, clerical speed/visual processing and phonological and visual reaction times tasks. Analysis of variance found main effects of: verbal modality, rapid naming, phonological reaction time and literacy attainment upon group; there were no significant interactions. One-way ANOVAs and independent samples t-tests found the lower performing literacy group performed significantly less well than the higher group on measures of verbal memory, rapid naming, phonological reaction times and reading and spelling. Reaction time tests were not normally distributed and were treated with caution; they correlate strongly with rapid naming. In the lower literacy group, significant correlations were found between reading and rapid naming, but not in the higher group. 28% of participants were found to have at least one area of cognitive processing in the below average range. Limitations of this study and recommendations for further research are discussed along with pedagogical concerns raised by the results.

Key terms: Processing speed, reaction time, short-term memory, working memory, modality

Acknowledgements

I would like to take this opportunity to communicate my heartfelt thanks to my children, Will and Meg. This journey started because of you. You are living proof that neurodiversity enriches us all. Your calm and constant reassurance that this thesis could be done, meant it was done. To my sister Gwen, for receiving the rants over the years with patience and responding with wisdom and for doing my share in the garden without complaint. Also, to my supervisor, Professor Chris Jarrold, for your unstinting support and guidance during the repeated interruptions that life sent my way. I have learned so much from travelling this path.

Thank you.

Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by a specific reference in the text, the work is the candidate's own work. Work done in collaboration with their assistance of, others, is indicated as such. Any views expressed in the dissertation of those of the author.

SIGNED.. DATE................................

Table of Contents

List of Tables

List of Figures

Abbreviations

ADHD – Attention Deficit Hyperactivity Disorder

ASC – Autistic Spectrum Condition

AWMA – Alloway working memory assessment

CTOPP2 – Comprehensive Test of Phonological Processing

DALP – Dyslexia Action Literacy Programme

JCQ – Joint Council for Qualifications

NFER – National Foundation for Educational Research, reading test

PA – Phonological Assessment

PS – Processing Speed

PT – Precision Teaching

OFQUAL – Office of Qualifications and Examinations Regulations

OFSTED – Office for Standards in Education

RAN – Rapid Alphanumeric Naming

RT – Reaction Time

SASC – SpLD Assessment Standards Committee

SDMT – Symbol Digit Modalities Test

SpLD – Specific Learning Difficulty

STM – Short Term Memory

SWST – Single Word Spelling Test

WM – Working Memory

Chapter One

1. Introduction

For decades, research has been conducted which has examined the links between academic attainment and certain cognitive processing abilities in children, (Daneman & Carpenter 1980; Denkla & Rudel 1976; Wagner & Torgesen 1987;) with phonological awareness (Snowling, Muter & Carroll, 2007), rapid naming (Georgiou, Papadopoulos, Kaizer, 2014), memory abilities (Alloway & Alloway 2010; Gathercole et al., 2016) speech and language deficits (Dockrell, Lindsay & Palikara, 2011), processing speed (Conway, Cowan, Bunting, Theriault & Minkoff, 2002) all cited as influencing factors. Despite an increased understanding of the difficulties they face, pupils with cognitive processing deficits continue to lag behind peers in educational attainment (Hall, Jarrold, Towse & Zarandi, 2015). This study will research pertinent factors affecting Key Stage (KS) 3 pupils in a mainstream UK secondary school with the aim of identifying relationships between cognitive processing and academic attainment in literacy

1.1 Background

With the exception of nationwide key stage (KS) 4 qualifications, no standardised approach to assessment currently exists in secondary schools in the UK. Consequently, no agreed formalised assessment of cognitive processing abilities takes place and, with the exception of initial baseline assessments that often take place in year 7 upon entry to secondary education, the majority of assessment in secondary school is conducted at subject level. After consultation on reforming the assessment accountability system for secondary schools, the government removed assessment levels and gave autonomy to schools to develop their own assessment systems (Department for Education, DfE, 2013). Currently, schools simply need to adhere to core principles of assessment which essentially require the system to be meaningful, transferable and to enable progress tracking (DfE, 2014a). In this model, teacher assessment of learning is formative throughout the year, with a statutory requirement for a summative assessment, by subject, at the end of the academic year (Association for Achievement and Improvement through Assessment, 2015). These subject assessments will evaluate the pupils' performance compared to given criteria in the KS3 and KS4 National Curriculum (DfE 2014b).

Assessment of pupils who are not making expected levels of progress can be more detailed. When the Special Educational Needs and Disability (SEND) legislation was updated in 2014, the 'Assess, Plan, Do, Review' (DfE 2014c p. 86) cycle of tracking and provision was introduced for the first time in the guidance documentation and described in detail. The onus is placed upon the subject teacher in a secondary setting, working in partnership with the Special Educational Needs and Disability Coordinator (SENDCo), to assess a pupil's needs at the outset of teaching and then to differentiate provision to enable the pupil to access the curriculum. According to the SEND legislation, the subject teacher should base the teaching provision on an analysis of teacher assessments, previous knowledge of the pupil, school data, parental opinion and pupil voice. Where outside agency advice has been requested, then this too should be taken into consideration. The above cycle has 'review' built into it so that if subsequent teacher assessment finds that progress is not being made, then referral to the SENDCo is advised for perhaps some small group or 1:1 intervention and/or more detailed assessment (DfE 2014c); there is no agreed consensus on which assessments should take place.

Consequently, assessments carried out with KS3 and 4 pupils do not necessarily include those which measure cognitive processing abilities; this will depend on the qualification level, time available and experience of the SENDCo (Joint Council for Qualifications, JCQ, 2018) and SEND staff. Once pupils reach year 9, schools are permitted to assess individuals and use the resultant measures for exams access applications to awarding bodies (JCQ, 2018), however this does not always result in cognitive processing assessments taking place.

Access arrangements can be applied for as a result of a below average score in a number of areas. One assessment of cognitive processing of a standard score of 84 or below will qualify the pupil for 25% extra time in public examinations, two measures in different areas of processing of a standard score of 69 or below are required for up to 50% extra time. Standardised measures of processing speed, phonological awareness, sight word reading efficiency, short term memory and working memory, in addition to reading and spelling/writing scores are eligible for making an application to the examination awarding bodies (JCQ, 2017).

A pupil might be referred to an assessor by a teacher who is concerned about their reading ability. A reasonable adjustment of provision of a reader or computer reader may be the outcome of such an assessment. If awarded, such support would allow a human reader to read the content of any exam paper to a pupil, with the exception of papers with the purpose of examining reading ability such as GCSE English Language. For English language testing papers, a computer reader can be awarded; the exam script is loaded onto a computer and the pupils listen through headphones to the paper being read to them. Both types of reading support also allow for the pupil to be supported in reading their own work back to them. The JCQ regulations state that if a pupil has already qualified for a reader/computer reader based upon: word reading, reading comprehension of continuous text, reading speed, rate, accuracy or fluency upon obtaining a standard score of 84 or below in assessment, then he or she can be awarded 25% extra time on the basis that asking a reader to repeat text, or rereading text using a screen reader can be time consuming. No additional assessment of processing speed, phonological awareness or memory is required.

Similarly, if a pupil has qualified for a scribe in examinations on the basis of having a rate of free writing or a word spelling standard score of or below 84 (with incomprehensible spellings) or due to illegible handwriting, then he or she can be awarded 25% extra time, as dictating and asking a scribe to read back what they have written takes additional time (JCQ, 2017). Again, as in the case of a reader/computer reader, even if a pupil is awarded extra time, cognitive processing abilities may not necessarily have been measured. A pupil with observable difficulties can go through their entire educational experience without being assessed to see if a cognitive processing deficit is affecting their ability to access learning and/or to evidence their knowledge and understanding in written responses; consequently, reasonable adjustments to support learning in the classroom may not be made.

Where a pupil has been found to have some form of difficulty affecting their academic performance, which subsequently qualifies them for exam access arrangements, then reasonable adjustments must become their 'normal way of working' in the classroom (JCQ, 2017 p17; Equality Act, 2010). For example, a pupil with slow processing speed might be given longer to complete assignments or be able to showcase understanding through bullet points rather than full written responses. Therefore, it is important that the degree of deficit a pupil is experiencing is known and that classroom teachers and the SENDCo liaise to ensure that support is available throughout the pupil's academic career (JCQ 2017, Jones 2011).

A growing number of pupils are being identified as needing and qualifying for support. There has been a year-on-year increase in successful applications for exam access arrangements over the last 5 years in the UK; in 2017, 392,955 applications were successfully processed; 57% of these were for extra time of 25% (223,405). This figure represents an increase of 8.2% compared to the previous year (Gov.uk, 2017). These figures relate to GCSE and 'A' Level candidates. In total, 15.7% of pupils taking GCSEs and 'A' Levels were awarded 25% additional time in summer exams of 2017. This need for extra time in exams should also point to similar reasonable accommodations being made in the classroom becoming the normal way of working. However, if these deficits are not identified until year 9 as directed by the JCQ (see above), pupils' cognitive difficulties (excluding phonological awareness which is tested in early years) are often not explored from reception through to year 8, if at all, which may prove to be seriously detrimental to their academic attainment.

1.2 Research focus

The increase in the numbers of pupils being assessed for and awarded additional time in public exams, illustrates the growing awareness within education of the need to be cognisant of both pupils' underlying difficulties and the duty placed upon educational settings to make reasonable adjustments according to the Equality Act (2010).

A considerable body of research exists which concludes that certain cognitive processes correlate with higher level abilities and/or academic attainment. From this research, we can surmise that pupils with undiagnosed and unsupported cognitive deficits are at risk of becoming disadvantaged in the classroom. For example, those with working memory difficulties may need repetition and overlearning opportunities in order to transfer learning into long term memory (Bogaerts, Szmatec, Hachmann, Page & Duych, 2015). Pupils with weaknesses in phonological awareness and/or rapid naming deficits may need more time to read extracts in class in order to extract meaning (Savage & Frederickson, 2004), those with relatively weak phonological memory may benefit from pre-teaching of subject specific vocabulary as suggested by Tattersall, Wolf and Tyler, (2015). Additionally, those with handwriting speed difficulties may fail to keep up in class or complete class assessments successfully (Barnett, Prunty, Rosenblum 2018), and memory capacity has been closely correlated with: IQ (Kyllonen & Christal 1990); reading comprehension (Cain, Oakhill & Bryant, 2004); maths (Witt, 2011) and overall academic attainment (Alloway & Alloway, 2010,). From the existing body of research, there appear to be a number of potential cognitive processing difficulties affecting academic attainment. Whatever the causal factors it seems that pupils may benefit from early identification and intervention (Gathercole & Alloway 2008). Therefore, it is important to review the research whilst considering its relevance to KS3, UK, mainstream pupils. Analysis of the findings of this study will be conducted with existing research in mind.

1.3 Overall research aims

The overall aim of this research is to contribute to the existing body of literature and consider the degree to which assessment of cognitive processing abilities might be meaningful in examining the impact of memory and processing speed deficits on literacy attainment in secondary aged pupils. A review of previous findings is important in order to inform this study's direction and to evaluate conclusions already drawn. Critical evaluation of previous studies, will inform the focus of research. Analysis of links made between certain literacy abilities and cognitive processing will be evaluated. The specific research aims are:

i. to identify from previous research the extent to which information processing ability/speed and memory ability have been found to correlate to higher level abilities, specifically literacy attainment
ii. to critically evaluate the above research
iii. to calculate the incidence of cognitive deficit in this study's participants
iv. to draw conclusions concerning the impact of any cognitive processing deficits upon academic attainment from this study's research results
v. to recommend appropriate courses of action to educators to ensure that measures found to be correlated with literacy attainment specifically are investigated further with possible interventions in mind.

vi. to explore the need for further research

1.4 Value of research

Conclusions will be drawn from the analysis of this study's data; results will contribute to existing research. An objective assessment of the value of the results in contributing to the existing body of work informing pedagogical practice will be made with specific relevance to KS3 pupils in a UK mainstream setting. In addition, this research will provide an indication of the incidence of deficits in certain areas of processing speed and memory within a KS3 population in a UK secondary school.

Chapter Two

2. Literature Review

The aims of this literature review are to: examine some pertinent and current teaching challenges; review existing research of cognitive deficits which appear to affect academic performance; assess how these deficits impact upon attainment and to understand which existing interventions have been found to be beneficial in order to inform the basis and content of this research study; to identify detailed research questions.

2.1 Pedagogical concerns

Despite there being a legal requirement for exam access arrangements to also be the student's normal way of working, pressures from the curriculum might mean that pupils with memory or processing speed deficits cannot always be given additional time to complete work or process information in the time given, in the classroom (Rose, 2009). The new academic curriculum was adopted in the UK in 2014 with the aim of introducing more rigour to teaching and learning (DfE, 2014). In 2016/17 Childline saw an 11% increase in the demand for counselling support for exam stress compared to two years previously (NSPCC, 2018). Teachers have expressed concern that the increased weighting (for school performance tables purposes) loaded onto the core subjects requires that additional hours of teaching are now needed and that moving from modular to linear exams will require students to retain information for longer; this will need to be supported with frequent opportunities for reiteration (Cassidy, 2014), again taking more time. Teachers raise concerns that the timetable will be squeezed and that GCSEs will become "one long memory test". (Cassidy, 2014 p.11). The English Literature GCSE exam is now closed book; unseen texts are presented in the exam and students are required to critically analyse them with reference to literature they have been studying. Debate has taken place over whether or not it is meaningful to ask students to remember numerous pertinent and possibly useful quotes from literature they have studied, in order to compare and contrast them with a previously unseen text in the exam. An office of Qualifications and Examinations Regulations (Ofqual) spokeswoman responded to concerns that regurgitating texts is not required, rather an ability to show a deep understanding of literature studied (Stacey, G., 2018). On the other hand, Gordon (2017) believes that requiring students to comment upon minimally contextualised texts whilst comparing them to others they have committed to memory is outdated and can cause students to disengage from literature. Additionally, before the changes to the curriculum, maths students were provided with a formulae sheet; this is no longer supplied (AQA, 2018), perhaps placing a burden on memory for students.

Traditional ideas for classroom learning may have made it more difficult to implement support for students with cognitive processing difficulties in the past. Historically, the emphasis on pace in the classroom may have prevented pupils with cognitive processing difficulties, having time to apply meaningful strategies and accommodations to their learning. The promotion of pace can be traced back to government intervention in lesson delivery and specifically to the introduction of the Literacy Hour in 1998 in the primary National Curriculum (Lefstein & Snell, 2013). The Office of Standards in Education (Ofsted) inspections are summarised in reports which frequently referred to pace of lessons and the inference was that fast paced was good and slower pace was detrimental to learning (Cowley, 2012). Furthermore, the Primary National Curriculum (DfE, 2018d, p. 16) states that in English, reading development should be 'rapid' paced in Key Stage 1; in maths at all key stages, all pupils should be taught new concepts at 'broadly the same pace' (DfE, 2018d p.99). This seems counterintuitive as pace does not appear to have been defined by the government within the learning context (Lefstein & Snell 2013).

The pressures on the curriculum outlined above have by default demanded brisk pace in many classrooms. Academic research has suggested however, that fast paced lessons may disadvantage many students. For example, Lefstein and Snell (2013) concluded that slower pace is often more engaging and enables pupils to make considered, metacognitive responses to their learning. In particular, pupils with specific learning difficulties complain that they have difficulty keeping up with the pace of their lessons (Rose 2009). Indeed, pedagogical concerns about the individualised approach to teaching and learning which allows pupils to learn at their own pace were in sharp contrast to governmental (specifically Ofsted's) assertion that "brisk pace" was synonymous with effective teaching and learning (Cowley, 2012 p.17). Reassuringly perhaps, pace related comments are hard to find in reports published in 2017 onward. This apparent change of emphasis is welcome and an important one, and one which lends itself to accurate assessment of need for classroom learning, but is it possible in the secondary setting given the new more vigorous demands of the curriculum? This study aims to identify the incidence and significance of cognitive processing deficit which may affect a student's ability to learn and keep pace within a KS3 cohort.

It is difficult to gauge the true incidence of cognitive processing difficulties in the classroom when individual assessments are not carried out on an individual level. Research has shown that conditions such as Attention Deficit Disorder (ADD), Attention Hyperactivity Deficit Disorder (ADHD) (Dovis, Van der Oord, Wiers & Prins, 2013, Shanahan et al., 2006) SpLD/Dyslexia (Fostick & Revah, 2018, Kibby & Long, 1997), DCD/Dyspraxia (Sumner, Pratt & Hill, 2016) and Dyscalculia (Bugden & Ansari, 2016; Chinn, 2016) all present with memory and/or processing deficits. In addition, there are other difficulties that affect classroom learning, for example research has shown that individuals with Autistic Spectrum Condition (ASC) often process information more slowly (Haigh, Walsh, Mazefsky, Minshew & Eack, 2018) and have deficits in verbal short-term memory (STM), (Poirier, Martin, Gaigg & Bowler, 2011). A raft of speech and language difficulties exist which have auditory processing difficulties at their core; research shows that individuals diagnosed with Specific Language Impairment (SLI) for example, experience deficits in auditory processing speed (Haresabadi & Shirazi, 2015). Prevalence figures offered by support groups hover between the 5-10% of population range for many of these developmental disorders (BDA, 2018; Adders, 2018) and 1% for ASC (NAS, 2018) but comorbidity confounds the figures; Pauc, (2005) found comorbid conditions in 95% of individuals diagnosed with either dyslexia, dyspraxia, attention deficit disorder (ADD), attention deficit hyperactive disorder (ADHD), obsessive compulsive disorder (OCD) or Tourette's. There were 8, 735, 098 pupils in English schools in 2017-18 (DfE, 2018); we cannot know precisely how many of these pupils are experiencing cognitive deficits which may be their impeding progress in the classroom without specifically assessing individual pupils.

As a result of the conclusions of numerous research studies into the impact of cognitive deficits upon academic attainment, Educational Psychologists, Specialist Teachers, Speech and Language Therapists and other Specialist Assessors assess recognised areas of weakness in order to determine if a specific difficulty is present for which reasonable accommodations and interventions can be offered. Such assessments include tests for short-term memory and working memory (Alloway 2007; Reynolds and

Voress 2007), phonological awareness, phonological memory, rapid automatised naming (Wagner, Torgesen, Rashotte & Pearson, 2013), and clerical speed/visual processing (Smith, 2010) to name a few.

Professional bodies are in agreement with regard to which areas of assessment yield relevant information regarding a learner's cognitive deficits with the aim of appropriately supporting them. For example, the SpLD Assessment Standards Committee (SASC) publish guidance on which research based standardised assessments are acceptable when producing a Disabled Student Allowance (DSA) for undergraduate students, (SASC, 2016).

However, research conclusions vary as to which individual or combination of cognitive processes have the greatest effect on (or are better predictors of) academic attainment. Some researchers have concluded that certain cognitive processes determine levels of general intelligence, (Kyllonen & Christal, 1990). Others that cognitive processes for example, working memory, are more closely correlated to academic attainment than fluid or verbal intelligence (Alloway & Alloway 2010). Much of the research has compared one cognitive process to another (Kail, Hall & Caskey, 1999; Kruk & Ruban, 2016), others have examined whether or not a combination of areas of weakness adversely affect academic attainment (Wolf & Bowers, 1999). Others still have questioned whether or not researchers are asking the right questions and if correlations between performance in different areas of processing/performance simply demonstrate that common processes are being tapped into from differing angles of investigation (Shipstead, Harrison, Engle 2016).

Some of the cognitive processes that have been extensively researched in relation to academic attainment are examined in greater detail below. The ultimate objective of the conclusions of such research must be to identify and inform pedagogical practice in order to ensure that interventions are relevant and successful. (Rose 2009; Snowling & Hulme, 2011).

The first area to be examined is that of phonological awareness as interventions in this area appear to be widespread, with every reception class child in the UK being introduced to some elements of phonological instruction in their first year of schooling (Rose, 2006).

2.2 Phonological awareness

The term phonological awareness (PA) refers to an individual's awareness of the different units of sounds found in speech (Wagner et al., 2013). Learners' abilities in phonological awareness have been extensively researched over the years; it is widely accepted that a weakness in discerning, deleting, manipulating, decoding (analysis), encoding (synthesis) and/or recognising sublexical units such as phonemes, syllables, onset-rime and body-coda , ostensibly the structure of sound within language, can cause a detrimental effect on literacy attainment, specifically reading and spelling (Stanovich 2000; Vellutino, Tunmer, Jaccard & Chen, 2007; Wagner & Torgesen, 2007).

2.2.1 Existing research conclusions

Numerous research studies have found a correlation between PA abilities and literacy attainment in the academic setting with different elements of PA being found to correlate with reading acquisition across the age ranges. For example, Muter, Hulme, Snowling and Stevenson (2004) in a two-year longitudinal study conducted with reception year pupils, concluded that decoding ability in the form of letter knowledge and phonemic awareness, predicts reading acquisition, whereas grammatical skills, existing word recognition ability and vocabulary knowledge predict reading comprehension. Conversely, Garcia and Cain (2014), conducted a meta-analysis of 45,000 research subjects which included both children and adults and found a positive correlation between reading comprehension and decoding ability. Decoding is the process of an individual attacking a new and unfamiliar word, not already recognised by sight, and deconstructing it into its constituent letters, ascribing phonemes to the graphemes and building these back up to form a word which they either recognise from their lexicon or add to it. Interestingly, Garcia and Cain found that this relationship decreases with age as word recognition becomes automatised and reliance on decoding is limited to new and unfamiliar vocabulary. More recently Snowling and Melby-Lervag (2016), conducted a review of children with family risk of dyslexia and concluded that deficits in PA and decoding were indeed enduring developmental factors thereby confirming the continuing difficulty that learners with PA deficits have when decoding new and unfamiliar subject vocabulary.

The research community holds differing opinions regarding which elements of phonological processing cause the greater impact on acquisition of reading: as discussed above, some research shows that phonemic awareness i.e. knowledge of phoneme/grapheme correspondence, is the main factor (Mcgeown & Medford 2014). Melby-Lervag, Lyster and Hulme, (2010) conducted a meta-analysis of 235 studies in order to examine a review of the relationships between phonemic awareness, verbal short-term memory (STM) and rime awareness among learners with dyslexia compared to typically developing same age peers and children who had been matched on reading ability. The review concluded that the greatest deficit experienced by learners with dyslexia was in phonemic awareness when compared to both control groups. Smaller but still significant differences were found in rime awareness and verbal STM with both groups.

Zeigler et al., (2010) however, found the broader elements of phonological awareness, rather than phonemic awareness, to be strong predictors especially so in the opaquer orthographies of the five languages studied in their research. However, their chosen assessment of phonological awareness was deletion of initial phonemes of aurally presented words and pseudo words; phonological awareness of larger grain sizes was not assessed. This test of phonological awareness is the closest to phonemic awareness and as such does not test the full range of phonological awareness required to recognise all of the speech sound components of language such as syllables, onset and rimes or blends (Wagner et al., 2013). Sermier Dessemontet and de Chambrier (2015) found that both phonemic knowledge (phoneme/grapheme correspondence) and phonological awareness were predictors of single word and pseudo word reading ability in their study of 129 6-8-year olds identified with mild to moderate learning disabilities. Similarly, Zeigler et al., (2010), found phonological awareness to be the strongest predictor of reading ability in 1265 grade 2 children. Despite these differences in opinion the research community appears to be agreed that phonological awareness, as a broad descriptor, is correlated with literacy acquisition.

Phonological awareness ability is also closely associated with spelling ability. Moll et al., (2014) examined differing phonological processes in 1062 typically developing 7+ year olds in learning in 5 different European languages and found that phonological processing was a predictor for spelling (and reading) in all languages studied. Furthermore, recent research has concluded that improved PA, through training, directly transfers to improved spelling ability (Vander-Stappen & Reybroeck, 2018). In this study they found separate and distinct benefits from PA training that could not be attributed to rapid naming ability (see below). This study was conducted with French speaking Belgian primary aged children. Bernstein (2009) found that English speaking American children with dyslexia made more phonological errors than orthographic in their spelling; in children with dyslexia a higher incidence of incorrect vowel substitutions was found. Learners with spelling difficulties struggle with producing written work which reflects IQ and a diverse verbal lexicon, (Connelly, Dockrell, Walter & Critten, 2011), suggesting that PA deficits can, through reduced spelling ability, affect written ability and therefore literacy attainment.

2.2.2 Differing orthographies

The opacity of a language appears to determine the influence of differing phonological factors. English is an opaque language in that phoneme/grapheme correspondence is not consistent; consider the pronunciation of *cough, thought, though, rough, through*; whereas in Spanish for example, individual graphemes consistently represent the same phonemes. Additionally, syllabic structure in more transparent orthographies tends to be of a uniform consonant/vowel structure, for example, Spanish: hi/jo - *son*, ma/ri/po/sa – *butterfly*, pen/sa/mi/en/to – *thought* (Goswami 2008). We can see that in the example of the word *thought*, that one syllable in English can be represented by seven graphemes. Both the degree of opacity and syllabic structure render the more transparent language easier to decode phonetically, so caution must be used when citing research conducted in other languages: Zeigler et al., (2010) analysed studies from 5 different languages, none of them English and found that PA was the main factor in predicting reading performance in all languages examined. Sermier Dessemontet and De Chambrier (2015, p.1), analysed data from research carried out with French and German speaking subjects found that the language spoken was not a significant predictor of success in literacy attainment in primary aged children with “intellectual difficulties”. Goswami (2008), determined that even where a language appears to be of similar complexity, for example Welsh and English, the degree of transparency affecting decoding may well differ and affect the rate of early reading acquisition.

2.2.3 Teaching interventions

Snowling and Hume (2011) state that it is now well established that effective reading interventions for dyslexic learners involve PA and letter/sound correspondence. Meta-analyses of research studies carried out with English speaking participants have found that systematic phonics teaching does have a positive impact on reading acquisition (Ehri, Nunes, Stahl & Willows 2001; Torgerson, Brooks & Hall 2006), they also conclude that as long as the teaching is systematic then there is no significant difference between the efficacy of synthetic and analytical phonics. The difference between synthetic and analytic phonics is that the former teaches phonemes discretely in isolation and the skill of blending them together in order to form words whereas in analytic phonics the learner is encouraged to discover the phoneme aurally or visually or both within words and to infer the phoneme/grapheme correspondence (Torgerson et al., 2006; Cochrane & Binns, 2015). Many researchers note that it is important to have a multi-faceted approach to literacy interventions, not one that relies solely on improving phonological awareness (Gonzales-Valenzuela & Martin Ruiz 2017; Snowling & Hulme, 2011; Bowers & Bowers, 2017; Kim, Hemphill, Troyer, Thomson, Jones et al., 2017) but rather one that looks at all aspects of reading activity and text analysis; see RAVE-O intervention below. It is important however to note that some studies and analyses have shown that the method of reading instruction appears to determine which cognitive processes are relied upon. McGeown, Johnson and Medford (2012) found that vocabulary skills predict word reading acquisition when sight word reading methods are taught.

2.2.4 Government response to literacy teaching

In England, the Department for Education has determined how pupils in Key Stage 1 should be taught to read based upon a review of literacy teaching in the Early Years commissioned by the Secretary of State (Rose, 2006). Sir Jim Rose, currently president of the National Federation for Educational Research, was invited to conduct the review which was published in 2006. The review was restricted to the assessment of synthetic phonics, Rose having asserted that there was not enough research available to determine if any other approaches were more successful. This assertion seems to contradict the depth and breadth of research available at the time (Wyse & Goswami, 2008). Rose perhaps unsurprisingly concluded in the review (2006), that synthetic phonics was the way forward and cited the success of a synthetic phonics intervention in Clackmannanshire (Johnston & Watson 2005) on the acquisition of reading by Key Stage 1 pupils. Michael Rosen (2006 cited in Hynds, 2007 p.273) asks the question "can it be replicated?" and at the time of Rose's review and conclusions, it had not been (Ellis, 2007; Wyse & Goswami, 2008). More to Rosen's point, he felt it could not be replicated as the research had not employed robust methods of ensuring similar conditions for control and intervention groups (Wyse & Goswami). Despite criticism of the research methods (Wyse & Goswami 2008; Davies, 2012) and academics arguing that the synthetic phonic approach was too narrow (Hynds, 2007; Moss and Huxford 2007 cited in Ellis 2007), the English government pressed ahead with this single stranded focus. The recommendations were adopted and changes were made to the primary curriculum for implementation in the academic year 2007-8.

2.2.5 Critique of the single stranded focus

Higher level reading is delayed for the recipient of synthetic phonics; reading for meaning (and fun) are not explored (Davis 2012). Concern was expressed that the method of phonics teaching chosen did not contextualise the learning of words (Wyse and Goswami 2008). Criticism centres around the concerns that synthetic phonics offers too narrow a focus and delays exposure to books. Teaching of synthetic phonics is fast paced and focusses on the synthesis (blending) of phonemes – all 44 phonemes are taught before contextual reading is introduced. The other elements of phonological awareness detailed above are not broached in the early years in a pure synthetic phonics programme. Interestingly the Clackmannanshire project informed but did not shape Scottish literacy policy; in Scotland they embraced many of the strands that successful reading outcomes require (Ellis 2007).

Research shows that phonics instruction improves the outcomes for the majority of children but those who fail to respond to this kind of intervention need a different approach and meet the criteria for a definition of SpLD/dyslexia (Snowling 2016, Rose 2009).

Analytic phonic programmes (for example DALP, 2015; Units of Sounds, 2017) also contain strands covering phonological awareness of sublexical units, morphological analysis, punctuation, etymology, syntax, metalinguistic terminology and semantics in higher level reading in addition to phonemic awareness. All of these strands need to be explored if weaknesses are to be effectively supported and if necessary, taught sequentially and explicitly to the struggling learner (Gonzalez-Valenzuela & Martin-Ruiz, 2017; Kim, et al., 2017). Regardless of the intervention approach, phonemic instruction appears to assist reading acquisition but a more comprehensive exploration of the English language spelling system is more beneficial (Bowers & Bowers, 2017).

2.2.6 Phonological awareness and research led interventions in the secondary setting

Despite the difference in opinion between researchers, academics and national governments, it has been widely accepted by teachers, academics and, researchers (Snowling & Hulme; 2012, Vander-Stappen et al.,2018) and the specialist support community that remedial intervention which targets phonological awareness, including phonemic awareness, has a positive impact on struggling readers and spellers. The Vander-Stappen et al., (2018) study is interesting as it suggests that phonological awareness can be improved and transference to improved literacy attainment evidenced in French speaking second grade pupils, when rapid naming (see below) elements of training are removed.

Snowling and Hulme (2011) assert however, that the research behind the implementation of intervention programmes is patchy for secondary aged pupils and beyond and calls for a "virtuous circle" (2011 p.1) of research followed by informed intervention to be developed. There appear to be only a minimal number of research studies conducted that have randomised controlled trial (RCT) design at the heart of their methodology in the UK secondary setting (Paul and Clarke 2016). Nonetheless some secondary schools in England do offer interventions and the efficacy of these specific programmes are assessed with effect sizes calculated where possible (Brooks, 2013).

2.2.7 Phonological awareness interventions

A student with a PA deficit of standard score <85 would qualify for extra time of 25% in exams if required. If their standard score was below 70, and they qualified in a different area of cognitive processing at this low score then they would qualify for 50% additional time (JCQ, 2017). This arrangement could only be awarded if it was the student's normal way of working. Classroom accommodations could include:

- reduced text reading

- use of a word processor and spellchecker or a scribe
- additional time to complete tasks
- not being asked to read aloud in class
- computer reader etc.
- access to a cumulative, structured, multisensory literacy programme
- opportunities for regular reading practice

2.3 Rapid Automatised Naming

Rapid automatised naming (RAN) is considered to be another activity which draws upon phonological processes (Wagner et al., 2013). RAN describes the ability to name presented stimuli at speed. In assessment of RAN, objects, colours letters and/or digits are presented in series or discretely and the participant is required to name them as quickly as possible. Performing this task requires the visual recognition of presented stimuli and the retrieval of previously stored phonological information from long term memory, before it is verbalised. Therefore, although phonological in nature, the process of naming object, colours and alphanumeric stimuli also requires visual processing (Wagner, Torgesen, Rashotte & Pearson, 2013).

Rapid automatised naming tasks are scored by measuring the speed at which an individual can recode the visually presented symbols into speech. Researchers argue that this process coupled with the ability to refer the phonologically recoded information to the individual lexicon play an important role in early reading acquisition (Araujo, Peterson, Ries & Faisca, 2014; Wagner & Torgesen, 1987).

2.3.3 RAN and presentation of stimuli

Stimuli in RAN assessments can be presented discretely or in series. Georgiou, Parrila, Ciu and Papadopoulus (2013) assert that RAN stimuli presented in series replicates the presentation of reading text and both reading and rapid naming processes require ‘rapid execution’ of similar cognitive processes (Kail et al., 1999, p.312). Serially presented stimuli are widely accepted as the optimum format for RAN tasks as this construct most closely correlates with reading ability and or acquisition (Stanovich 1981 cited in Kail et al.,1999). Consequently, the assessments used by many researchers and assessors follow such a format (Savage & Frederickson et al 1997; Wagner et al., 2013)

2.3.4 RAN and double deficit theory

Using assessments constructed in the serial format described above or similar, many researchers have found that RAN is associated with reading acquisition and/or ability (Denkla & Rudel 1975; Kruk & Ruban 2016). Wolfe and Bowers (1999, p.415) asserted that in terms of reading disability, a “double-deficit” exists; that among poor readers, there are those who display a single deficit in phonological awareness, those who have a single deficit in RAN and those who experience a deficit in both. They found that children experiencing a single deficit in RAN also experienced difficulties with both word reading and comprehension. The learners experiencing dual deficits appeared to experience greater challenges in reading acquisition and fluency.

The double deficit theory continues to be upheld by researchers. For example, Powell, Stainthorpe, Stuart, Garwood, & Quinlan (2007), sought to determine: the true nature of RAN and its relationship with reading and exactly which cognitive processing deficits correlated with reading ability. Their conclusion agreed with Wolf and Bowers (1999): their research supported the double deficit theory. In addition, RAN deficits were found to exist in isolation of phonological awareness and to correlate with degree of reading deficit. Arujo, Pacheco, Faisca, Peterson and Reis (2014) similarly confirmed the existence of participants with a double deficit in addition to participants with either single deficit phonological awareness or RAN in their study which compared 22 dyslexic pupils to 22 non-dyslexic pupils, all with IQs within the normal range. However, their RAN conclusions may have been confounded by their choice of letters presented in the alpha (letter naming) element of the task. The graphemes chosen were <d>, <o>, <p> and <t> and so the speed of naming may have been reduced due to grapheme confusability difficulties (Jones, Obregon, Kelly & Branigan, 2008) or by phonemic similarity causing task switching difficulties between <d > and <p> (Jones, Snowling & Moll, 2015) experienced by some dyslexic learners. These additional difficulties may have increased the response time of the dyslexic participants in addition to the time taken for visual sequencing, matching or retrieval of orthographical and phonological codes (Wolf & Bowers, 1999). Other research studies (Powell et al., 2007; Nelson, Lindstrom, Lindstrom & Denis, 2012) have used The Comprehensive Test of Phonological Processing (CTOPP) which asks participants to name letters that have reduced possibility for creating orientation and phonemic confusion viz.: <a>,<t>,<s>,<k>,<c>,<n>; this difference between RAN alpha stimuli used, indicates that caution needs to be exercised on the part of the reviewer when comparing studies.

2.3.5 Domain involvement in RAN

Differing opinions exist concerning which underlying cognitive processes are correlated with deficits in the speed of rapid naming. There are those whose research has led them to conclude that RAN is a manifestation of phonological awareness processes (Wagner & Torgesen, 1987). Others have concluded that RAN is closely correlated with: global processing speed (Kail et al., 1999); visual processing speed (Stainthorpe et al, 2010); or naming speed (Jones et al., 2016).

Some researchers have asserted that RAN does not exist as a separate entity to phonological processing as a whole. Savage, Pillay and Melidona (2007), designed a research study that aimed to separate out RAN from other phonological skills in order to determine which component parts of RAN contribute to spelling ability and therefore accurately target intervention in line with Snowling and Hulme's "virtuous circle" (2011, p.81). They found a strong correlation between RAN and response time and a weaker correlation between response inhibition and alphanumeric RAN. A strong correlation was also observed between nonsense word reading and alphanumeric but not picture naming RAN, leading to their conclusion that the relationship between alphanumeric RAN and nonsense word reading is as a result of both tasks summoning decoding skills; therefore, they conclude that RAN as a whole does not have a role in reading ability that is independent from phonological processing.

As mentioned above, Kail et al., (1999) found that naming times were predicted by processing speed (PS), however the PS tasks administered in this study were both pencil and paper tasks and any fine motor difficulties, often found to be comorbid with reading difficulties (Kaplan, Wilson, Dewey & Crawford, 1998) may have confounded the results. A finer-grained analysis of the tasks chosen to ascertain to what extent grapho-motor skills rather than fine motor skills would be necessary before concluding that general PS per se is the correlating factor (Suggate, Pufke & Stoeger, 2016). Furthermore, rapid visual processing was a requirement of both tasks, however neither naming nor articulation rates were assessed.

It is difficult to draw conclusions from processing speed tasks when the differing individual cognitive processes involved in rapid naming are not examined. More recently Jones, Snowling and Moll (2016) having acknowledged received opinion that RAN is related to reading fluency, used an automated rapid naming task combined with a Stroop-switch task in order to isolate the individual elements of the cognitive processes involved in rapid naming and concluded that dyslexic learners experience a delay at the naming phase of the task in comparison to non-dyslexic learners. The response time was increased when the Stroop-switch task was made more demanding by the insertion of visually or phonemically similar letters at the point of task switching to colour naming. This delay indicates either a speed of processing deficit or difficulties in inhibition of response causing an increase in the time taken to name the present array of stimuli. The researchers acknowledge that the question of which elements of reduced RAN performance are responsible for the relationship with reading difficulties remains unanswered but it seems that more recent research is pointing in the direction of processing speed abilities rather than phonological awareness. Kruk and Ruban, (2016) found that a strong performance in young children on timed visual processing tasks predicted faster nonalphanumeric RAN times and that untimed visual problem-solving abilities correlate with early alphanumeric RAN performance. They attribute the relationship between visual processing and RAN in the early years to a less automatised visual recognition of symbolically represented information although visual processing deficits have been found to predict RAN in adults (Jones et al., 2008).

2.3.6 The effect of age upon RAN performance

Studies across different age groups have found a correlation between RAN and reading. Kail et al., (1999) found that RAN ability correlated with age and; that RAN rates could be predicted by age related gains in processing speed. Studies have found RAN to predict reading acquisition and/or ability in pre-schoolers (Georgiou, Tziraki, Manolitsis, Fella 2013), primary age children, (Koponen, et al., 2016), secondary age Cantonese speaking children (Chung, Ho, Chan, Tsang & Ho 2011) and adults (Jones et al., 2015).

However, Georgiou, Papadopoulos and Kaiser (2104) propose that although RAN is correlated with reading throughout the school years, the relative impact of processing components of RAN which causes a deficit changes with age. In a 10-year longitudinal study they found that initially the pause between vocalisation of stimuli items was a greater factor in RAN deficits than articulation rate. As the children progressed through school years, they found that the pause rate diminished as automaticity of processes increased and articulation rate became the main predictor variable.

2.3.7 RAN across differing orthographies

Before drawing conclusions from this study and from the many studies which have investigated the nature of RAN and its relation to reading, literacy and consequently academic attainment, the relationship between the complexity and transparency of the orthography of the language being read and the strength of RAN as a predictor of reading should be examined. Georgiou et al., (2014) investigated the componential processes involved in RAN of Greek speaking children. Greek is a transparent orthography i.e. grapheme/phoneme correspondence is regular and therefore predictable. Finnish, for example is considered to be one of the most transparent orthographies and English one of the most opaque. It has long been believed that RAN plays a greater part in reading acquisition in transparent orthographies than phonological awareness (Ziegler et al., 2010). The consistency or transparency of phoneme/grapheme correspondence of an orthography relates directly to age and ease of reading acquisition, (Seymour, Aro & Erskine 2003, cited in Ziegler et al., 2010). Ziegler et al., as we saw above, analysed 5 European languages with varying degrees of transparency and concluded that the strongest predictor of reading was phonological awareness and that RAN held only a weak association. However, this study of Grade 2 children, picture RAN was the only chosen assessment and therefore alpha numeric, with its closer association to reading acquisition was not tested. Georgiou, Parrila and Liao, (2007) found RAN to be a strong predictor of reading fluency across three languages of differing complexity and form: English, Chinese and Greek. RAN was also found to have a strong correlation with reading accuracy for Chinese and Greek but not English.

2.3.8 RAN and effective interventions

The efficacy of targeted intervention for rapid naming deficits is not as well established as that for phonological/phonemic awareness programmes. Kail et al (1999) proposed that although naming time was related to word recognition, remediation may not be effective, as dual naming speed and processing speed deficits point to a systemic problem i.e. affecting all processing in general. However more recent researchers have concluded that RAN has a relationship with orthographical knowledge and those individuals who have low RAN scores are more likely to have less well-developed skills in this area. Conrad & Levy, (2009) found that pupils who had received orthographical training comprising words with repeated patterns of letters contained within them, made improvements in reading accuracy of new words but not word reading speed as measured by the Test of Word Reading Efficiency (TOWRE – Torgesen, Wagner & Rashottte, 1999). Here single words and nonsense words are presented in ascending order of difficulty and the participant is required to read as many items as they can within a time limit of 45 seconds. The RAVE-O programme looks to address fluency difficulties by incorporating orthographical knowledge into the teaching method. The programme incorporates phonology, syntax, semantic systems morphology into its classroom delivery and offers opportunities for repeated reading (Wolf et al., 2009. Although reading gains were made compared to control groups in the Wolf et al., (2009 study, results are confounded in terms of RAN deficits in that it is impossible to isolate the elements of the combined focus intervention that have a correlation with reading fluency and RAN. A meta-analysis of 400 studies researching the efficacy of repeated reading only of passages in improving fluency of reading concluded that this is a successful strategy if it is accompanied by previewing of the passage by a competent reader, for example the teacher, and that the passage is repeated at least 4 times (Lee & Yoon, 2017).

As above for PA deficit, a student with a RAN deficit of standard score <85 would qualify for extra time of 25% in exams if required. If their standard score was below 70, and they qualified in a different area of cognitive processing at this low score then they would qualify or 50% additional time (JCQ, 2017). This arrangement could only be awarded if it was the student’s normal way of working. Classroom accommodations could include:

- reduced text reading
- additional time to complete tasks
- not being asked to read aloud in class
- computer reader etc.

Whether phonological, visual, naming or as a result of global processing, RAN performance is measured in time taken to complete the task and the number of errors made is usually noted.

2.4 Reaction Times

A reaction time is the time taken for a participant to react to a stimulus; processing speed is the time taken to process a mental task. A number of different reaction time tasks are available to psychologists: a simple reaction time task measures the time it takes a participant to respond to a stimulus, a choice reaction time task as the term implies, presents the participant with a choice between two of more possible stimuli and they are required to choose and react accordingly and a discrimination reaction time task where a participant is presented with 2 or more stimuli and is required to react every time they see or hear a particular item (Colman, 2015). The latter two tasks require a greater degree of cognitive processing in order to respond.

At times the lines appear to blur between the RT and processing speed tasks. Some tasks are being identified as RT in nature by certain researchers and processing speed tasks by others, for example the Sternberg test is described as an RT test by Neubauer, Sternberg and Possner, (1996) and as a processing task by Vernon, Nador and Kantor, (1985).

For various reasons researchers attempt to break down the reaction into constituent parts to ascertain where any delays may occur or to find component parts that are shared with other measures of cognitive processing ability, for example articulation rate (Jones et al., 2015) or inter pause delay. There appears to be some interchangeability between the term reaction time and processing speed.

2.4.3 Reaction time and intelligence.

Neubauer, Rienman, Mayer and Angleitner, (1997) confirmed earlier findings by others (Vernon and Mori, 1992), of significant positive correlation between RT and intelligence as measured by the Ravens Advanced Progressive Matrices (APM), in 116 participants aged between 16 and 39. Participants were requested to complete the Hick-paradigm, which requires a response to between 1 and 4 visual stimuli by pressing a corresponding number of buttons, this task would also require visual spatial processing and memory especially for the 2 bit tasks. Additionally, the Sternberg Task required the participant to remember 1, 3 or 5 digits presented serially and then respond by pressing a ‘yes’ button when a single digit subsequently presented as the stimuli had been displayed in the previously presented string and a ‘no’ button if not (consequently, this RT test requires involvement of short term memory in order to be able to respond). And finally, the Posner task; here the participant is required to visually discriminate between letter name or shape. Same name/different shape could be ‘Bb’, same name/same shape ‘AA’, different name/different shape ‘Ba’. As with the Sternberg task this task requires additional processing abilities, i.e. visual processing. The correlations between the Ravens APM and all 3 tasks were significant. Visual processing skills and memory are also employed in the Ravens APM. Perhaps including some simple RT tasks that were measuring response to auditory and visual stimuli would have been a better measure of pure reaction time for correlation analysis. Deary, Der and Ford (2001) found higher correlation results with Raven (*n*=900) for a 4 choice Hicks test versus the simple (no choice, 1 item) test, confirming that correlation with intelligence tests increases with cognitive load. The Neubauer et al., (1997) study asserts that significant correlations between RT and processing speed were found but as we have seen the tasks used required significant amounts of processing so this would not be unexpected. Vernon (1986) concludes that more complex RT tasks are more likely to result in a strong positive correlation with intelligence tests than simple RT tasks.

2.4.4 Reaction times and academic attainment

In order to assess the literature which has examined RT in relation to academic attainment it is useful to find those studies that have used simple RT tasks (see above) in order to separate out as much information processing interference as possible. One such Indian study of 100 (females = 50) first year undergraduate medical students used both simple visual and auditory RT tasks to calculate if there was a correlation with academic success (Prabhavathi,et al., 2017). The simple visual RT (VRT) task required the participant to press a button when a red light came on screen; for the auditory RT (ART) task, they were required to press a button when they heard a signal through their headphones. For both genders, ART was faster than VRT, males were faster all round than females and participants with higher academic scores (based on a physiology test all participants had taken in 2016) achieved faster RT results. A Turkish study of 500 adolescents found similar results between males and females with a significant correlation between academic performance and RTs; the faster the RT, the higher the academic achievement. (Taskin, 2016). It is difficult however to find studies which have used simple reaction time tasks to examine the correlation with academic achievement in KS3 students in the UK.

2.5 Processing speed

In assessment terms, processing speed is the temporal measure of a given information processing task, in other words, how long a person takes to process the information they have been presented with. Some studies test processing speed (PS) at a local level, for example the RAN task where the participant processes each individual piece of information in turn, whereas others examine global processing where a participant is required to take in the whole picture in order to complete a task, for example the Cross Out Task (Woodcock & Johnson, 1990, cited in Ferguson & Bowey, 2005). The participant looks at a row of images and marks any that are identical to the example given at the beginning of each row.

2.5.3 Processing speed and age

PS increases with age throughout childhood (Case, Kurland, Goldberg, 1982; Ferguson & Bowey, 2004) and then begins to decline from early adulthood until in our eighties (Deary & Ritchie, 2016) and quite possibly beyond.

2.5.4 Processing speed and academic attainment

The ability to process information efficiently is one of the cognitive abilities that impacts upon academic fluency: reading, maths and writing fluency (Benner, Allor & Mooney, 2008). We have seen above that speed of processing as measured by RAN tasks has been found to correlate with both word reading and comprehension. Maths fluency refers to the ability to carry out mathematical procedures, operations and calculations efficiently and accurately (US National Council of Teachers of Mathematics, 2017). Fluency is a desired characteristic of any learner attempting to keep pace with classroom instruction.

A UK study has found a correlation between PS and mathematical calculations in grade 3 children, which is unique and separate from working memory ability (Cowan, Donlan, Shepherd, Cole-Fletcher, Saxton et al., 2011). Similarly, in grade 3 children in the US, Fuchs et al., (2006), found that PS was correlated with arithmetic. Additionally, they concluded that a sight word efficiency task, defined as a reading assessment, was correlated with arithmetical word problems. Fuchs et al., (2006) administered the Test of Sight Word Reading Efficiency (TOWRE, Torgesen, Wagner & Rashotte, 2012). This test is timed and is a measure of fluency and accuracy rather than reading ability; an untimed test would be a more analytical assessment of reading skills per se. The timed element ensures that PS is a component of this task and as a result it is not admissible as a reading test in JCQ applications for a reader for a disabled candidate (JCQ, 2017). TOWRE can however be used as evidence of need for extra time. The study concludes that sight word reading efficiency is correlated with performance on arithmetic word problems; the PS element of this task may well have been responsible for the correlation rather than reading ability. The correlation with reading comprehension Wolf and Bowers (1999) found with alphanumeric RAN, may in part explain the relationship between TOWRE results and arithmetic word problems as both assessments require reading serially presented information at speed.

Additionally pupils with comorbid development coordination disorder (DCD) and maths learning difficulties have been found to have visual-motor integration (VMI) deficits as measured by the Beery Buktenica (2004) developmental test of VMI which has a timed assessment component (Pieters, Roeyers, Rosseel, Waelvelde & Desoete, 2015).

The Symbol Digit Modalities Test (SDMT, Smith, 1982), is often used to assess information PS across a number of modalities: visual, phonological and fine motor, in cases of brain injury or degenerative illness. It is also used by SpLD assessors to provide supplementary evidence of PS deficit. One study found a positive correlation between the SDMT with General Average Intelligence in learners with ADHD (r=.30, p=.002), (Katz, Brown, Roth & Beers, 2011). Additionally, the study found a statistically significant difference between marginal means results on the SDMT for a group of 44 adolescents and adults with ADHD compared with a group of 65 adolescents and adults with ADHD and comorbid reading disorder, with the second group performing more slowly on this task.

2.5.5 Processing speed interventions

As stated above slow PS impacts upon fluency. We saw that in pupils with poor RAN scores, repeated reading was a useful intervention in improving reading fluency. Repeating tasks in order to gain mastery is known as Precision Teaching (PT). This technique of teaching through repetition, can be applied to a number of academic activities: learning number facts; reading and spelling; acquiring phonemic knowledge; retaining facts and so on. Roberts and Norwich, (2010) found that training Teaching Assistants to work with students on PT of key words, improved word recognition significantly and as a result, self-perception as a learner improved. Improvements gained through PT lead to enhanced academic fluency, (Wolf et al., 2007) whereas in contrast, an increase in education in terms of years spent studying, does not appear to enhance cognitive processing in cohorts of participants assessed whilst in their 70s (Ritchie, Bates, Der, Starr & Deary, 2013).

In addition to interventions, reasonable adjustments can be made in the classroom and exam situations:

- extra time in exams
- possibility of a scribe if handwriting is very slow
- assignments differentiated by amount
- alternative presentation of work e.g. bullet points
- access to a word processor for those with slow clerical PS
- voice to text software
- instructions reinforced in writing
- enlarged print for those with visual processing difficulties

2.5.6 Processing and memory

In order to learn, perceive and retrieve information we need to process it. In order to process information, we need to allocate cognitive resources to the task at hand; the magnitude of the cognitive demand is dependent upon the complexity of the task. Many researchers believe that information processing shares available capacity with memory and that the more processing of information a task demands, the more resources are drawn away from remembering. Daneman and Merikle, (1996) found through a meta-analysis of over 6,000 participants, that processing and storage capacity are more useful predictors of language comprehension than measures of memory alone. They found this to be the case when both vocabulary and mathematical processing was required by the task, concluding that processing plus storage combined was predictive of language comprehension ability regardless of whether language manipulation was part of the processing or not.

Barouillet, Bernadin and Camos, (2004) postulated a time-based resource sharing model of memory and processing; they concluded that working memory performance in adults varied depending upon the degree of information processing required by the task within a given time. They also noted that increasing the number of items delivered whilst keeping the time limit stable reduced the ability to rehearse to be remembered items, resulting in reduced numbers of items recalled. Magimairaj and Montgomery, (2012) examined domain specificity in their study of 61 Key stage 2 (7-11-year-old) children, they concluded that processing/attention appeared to be domain general when verbal working memory was being assessed. However, for one of the tasks, this study used a computerised counting span task which they report required the participants to count aloud the number of dots in arrays consisting of between 4 and 7 items. They state that the counting aloud ensured verbal processing was taking place. Whilst this is true, some pupils may have been able to process the information visually and recall the visual array when later ask to specify the number – any participant employing this strategy would be utilising visual spatial processing and working memory strategies; other tasks designed to assess working memory in the study were purely verbal in nature. Barouillet, Bernadin, Portrat, Vergauwe and Camos, (2007) also conclude in a later study that processing is domain general, as spatial processing disrupted verbal maintenance of to be remembered information. The participants in this study were undergraduates: 23 female and 1 male. Tasks included digit and letter reading and reaction time elements. The study does not appear to consider possible limitations caused by gender differences in rapid naming and reaction times – some research has shown that females are significantly faster than males at naming alphanumeric information and have slower reaction times than males when choice is increased if practice is not permitted (Der & Deary, 2009; Reimers & Maylor, 2006; Roivainen, 2011). Both areas of performance were recorded with this predominantly female cohort. Jarrold,Tam, Baddeley and Harvey, (2010) conclude in their study that processing of information is domain-general as observed in participants forgetting information as verbal or visual processing requirements were shown to limit the domain specific storage process.

Ferguson and Bowey (2008) found that age related changes in global PS predicted increases in auditory memory span in children ranging in age from 5 -13. Interestingly, the demographic analysis of the cohorts in this study does not include a breakdown of ethnicity, whereas one analysis of research into global and local perception has shown that East Asians are the better global processors (McKone, et al., 2010) even at second generation level. Both studies assessed Australian students although McKone et al's., (2010) conclusions were drawn from assessments of young adults. In this later study, the researchers contest that interference from this racial difference might affect the results of any study that does not mitigate for what they perceive to be an innate difference in processing.

2.6 Working memory

The term working memory (WM) was first used by Miller, Gallanter & Pribram (1960, cited in Conway, Jarrold, Kane, Miyake & Towse, 2008) to describe the process of holding information in mind whilst manipulating it, or working with it, in order to perform a task. Over the years academics have constructed theoretical models of working memory in order to try to help frame our understanding of the component elements of the cognitive processes believed to be involved in tasks requiring activation of working memory.

2.6.3 Some models of working memory

The models of WM are numerous and varied in nature; a few are described below. Baddeley and Hitch (1974, cited in Baddely, 2000) proposed a three-part model of working memory which included a phonological loop where verbal information is temporarily stored, a visual spatial sketchpad where images and spatial information are held and the central executive (CE) which is representative of the processes involved in planning and organising of information. Later Baddeley came to realise that this somewhat simplistic model lacked representations of communication/links to long term memory and revised their model to include what they termed, the episodic buffer (Baddeley, 2000).

Cowan's embedded processes working memory model does not recognise domain specific elements of storage and processing, rather he postulates that working memory is temporarily activated from long term memory and hones in on a particular piece of information that needs manipulating as is required. This model suggests that resources are shared between storage and processing. Flexibility is required in order to determine if more focus should be placed on storage of information or the processing demands of any task and this is controlled by the focus of attention, which serves a similar purpose to Baddeley and Hitch's central executive. Initiation of working memory is not always a conscious process, automatised responses can be activated subconsciously.

In 2009, Oberauer presented a design of an architectural model of WM. In his model the region of direct access (DA) is the area in which information retrieved from long term memory (LTM) is manipulated alongside the presented stimulus. Content and context are simultaneously held whilst the focus of attention selects and manipulates the relevant piece of information whilst holding all other aspects in place. Information not immediately required can be removed from the region of DA and stored in LTM to be retrieved again if necessary. Limits of capacity are created by both the content and contextual representations held in space within the region of DA. Oberauer offers a seemingly more complex model of WM but the architectural nature allows for declarative representations, procedural aspects and the focus of attention to be represented schematically. The architectural design of this model represents the link between the declarative and procedural parts of WM as a bridge between the two. Oberauer asserts that both meanings of bridge are relevant to its function: bridge as a connector of two entities, and bridge as a control centre. The bridge holds the procedural task, for example adding 2 to a series of numbers. The focus of attention holds the task to one digit at a time and how to add 2 is held in procedural memory. Oberauer asserts that the bridge holds a single action at a time. Already learned procedures held in LTM can affect the execution of the task held in the bridge if activated. Any well established and oft repeated process held in procedural LTM can interfere with the task held by the bridge either by overriding or delaying the execution, for example, in a Stroop task. Oberauer's model suggests that declarative WM and procedural WM are separate systems that operate in parallel, with both communicating with LTM and are connected by the bridge.

Ericsson and Kintsch's (1995) theory suggests that different storage systems blur during complex tasks – for example information might be held in short term memory whilst experiences of similar situations are simultaneously retrieved from long term memory.

Different theoretical models have been developed from research and in turn been tested by further research in order to ascertain which cognitive processes are involved in WM and how they interact. The conclusions drawn from psychological enquiry differ in many ways, in terms of: whether or not WM capacity is governed by processing speed (Case, Kurland & Goldberg, 1982); whether WM is a separate entity (Baddeley & Hitch, 1984) to long-term memory (LTM); whether it is domain general in nature (Kyllonen & Christal, 1990) or domain specific (Shah and Miyake, 1999; Bayliss et al., 2003) and even to the extent of the number of specific domains contained within WM and within the subsystems therein viz. within processing and storage. Researchers hold differing opinions on whether memory and the processes involved in manipulating to be remembered information are domain general or domain specific.

2.6.4 Domain specificity

In line with this question of domain specificity, opinion is mixed as to whether separate verbal and visual spatial domains exist in working memory as suggested in the Baddeley (1984) model. There are those that believe that believe that WM is domain-general (Kyllonen & Christal, 1990) others, for example, Oberauer, Suss, Schulze, Wilhelm and Wittmann (2000) conclude that WM is multi-faceted and domain-specific. Oberauer et al., (2000) proposed that there are three separate 'facets' to WM: spatial, numerical and verbal. Their conclusions were defined by the nature of the tasks they used to assess WM. However, there are some concerns regarding the categorisation of those tasks. For example, the backwards digit span task is classed as numerical but was presented visually, the participant might employ verbal rehearsal and no number calculation was required; rather, only the ability to manipulate a string of information was measured. For the star counting test, the content domain was designated as numerical. Stars were presented on screen and participants were instructed to count them in one direction or another depending on whether or not they saw a plus or minus sign. The meaning of the sign was reversed after seven items at which point the participant was required to count backwards for plus and forwards for minus. Significant content is directional and therefore spatial in nature and yet was designated as a numerical task. The Stroop-switch element may also confound the working memory emphasis of the task. None the less their findings are in sympathy with the Baddeley and Hitch model of separate WM domains.

The complexities around defining working memory and the variation in modelling theory is examined by Miyake and Shah (1999). They comment that the range and diversity of theory and models is confusing for all who attempt to study it – defining it is a major problem. After inviting eleven sets of authors to comment on eight separate aspects of

WM from basic mechanisms to biological implementation, the following definition was fashioned. "Working memory is those processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition, including novel as well as familiar, skilled tasks....." (Miyake & Shah, 1999).

In addition to the above, the invited researchers concluded (Miyake & Shah, 1999) that: WM is a complex construct that does not underpin tasks in isolation from other processes, neither in theoretical models nor in neurologically based research; WM is required for complex, higher order cognition and is not purely for temporary storage which facilitates manipulation of information; the CE serves a purpose in the processing and organization of information when held in working memory; the limited capacity of WM is caused by a multitude of possible factors, interplay between different domains is more likely than a domain general construct; long-term knowledge can facilitate WM processes (Conlin & Gathercole, cited in Jarrold, 2017) from which we can infer that reduced long-term knowledge could act as a constraint upon WM performance.

2.6.5 Working memory correlations

WM is a much researched and postulated paradigm. From a pedagogical point of view, the importance of this research activity lies in identifying where deficits and difficulties in WM might occur, how they can be measured reliably and to what extent they impact on learning and if they can be supported and/or ameliorated. It is important to know how WM performance correlates with other processes and abilities. Those that have been studied to a greater extent are: short term memory (STM), (Conway et al 2001; Daneman & Merikle, 1996; Oberauer et al., 2000), attention, processing speed (Bayliss et al., 2003; Case 1982; Dovis, Van der Oord, Weirs & Prins, 2013; Fry & Hale 1996; Jarrold 2017) intelligence levels (Kyllonen & Christal 1990), language comprehension (Daneman & Carpenter 1980) and academic attainment (Cain, Oakhill & Bryant, 2004; Swanson & Jerman 2007; Gathercole, Woolgar, Kievit, Astle, Manly et al., 2016).

WM consists of STM and the involvement of the central executive (CE) which organises the manipulation of information into and out of WM and LTM as needed, (Dovis et al., 2013) thus suggesting that WM and STM share certain characteristics. STM is a store for holding but not manipulating information for short periods of time. Engle, Tuholski, Laughlin & Conway, (1999) explore the different theories concerning the similarities and differences between WM and STM. They conclude that they are different but "related constructs" (Engle et al., p325), along with Conway, Cowan, Bunting, Therriault and Minkoff, (2001) Engle et al., found that STM was not a significant predictor of fluid intelligence whereas WM was, suggesting that differences existed between them. This tendency is not always upheld, for example Bayliss, Jarrold, Badderley and Gunn (2005) found that complex task results were no better predictors of higher level ability than simple span tasks, although this contrasts with their earlier paper (Bayliss, Jarrold, Gunn & Baddeley, 2003). Unsworth and Engle (2007) also concluded that STM and WM both correlate at a similar level with higher level abilities, when longer spans were presented in the STM tasks. They assert in their meta-analysis that the tasks chosen in some studies were in fact measuring the same processes. They also note that the proportion correct score: a score being awarded for each digit remembered in its correct place in the sequence delivered, as can be found in the Test of Memory and Learning 2nd Edition (TOMAL2), (Reynolds & Voress 2007); rather than absolute scoring, (CTOPP2) ,Wagner et al., 2013) correlates more highly with higher-order skills.

The above suggests that the tests selected to assess a cognitive process can affect conclusions drawn. For example, Conway et al., (2001) concluded that WM capacity is a good predictor of fluid intelligence but that STM and PS are not. However, the three PS assessments administered in this study each demanded an element of fine motor skills in order to complete the task and any difficulty with dexterity or clerical PS may have confounded cognitive PS measures. Indeed, untimed fine motor skills tasks have been found to be a significant predictor of verbal STM, spatial WM, mathematical and reading attainment in preadolescent children (Geersten, Thomas, Larsen, Dahn, Anderson et al., 2016).

Some researchers have asserted that WM capacity is correlated with PS (Fry & Hale, 1996; Kyllonen & Christal, 1990). The question of the relationship between PS and WM capacity is an important one. Case et al., (1982) found that developmental increase in WM capacity is accounted for by a developmental increase in PS – that capacity remains the same but the increasing speed with which we can process information as we mature allows more items to be manipulated in WM. Bayliss and Jarrold (2003) found that a domain general processing efficiency accounted for unique variance in verbal WM tasks. Furthermore, Jarrold, Mackett and Hall (2014) in assessing the relationship between the component parts of working memory, found that the processing efficiency element of WM was more closely correlated with teacher assessment of inattention in the classroom than measures of WM as a whole. The extent to which information processing efficiency contributes to WM capacity is an area of ongoing academic research.

Researchers have found WM capacity to be a significant predictor of intelligence. Kyllonen concluded that WM was in fact Spearman's g, the general factor in human cognition (1996 p.49). Touvra, Spanoudis and Demetriou (2016) agree; they concluded that WM and not PS nor attention was a predictor of intelligence: either fluid or crystallised. However, the WM assessments they employed included a demanding verbal complex span task whereas none of the PS tasks were verbal in nature. They concluded that internal consistency amongst the four PS tests was high and that they were therefore reliable measures of PS although the assessments were measuring visual PS only. It might have been interesting and meaningful to compare variables assessing domain specific abilities across the differing cognitive processes. Neuro-imaging confirms that similar areas of the brain are involved in both WM and Gf tasks regardless of domain and that the areas of the brain involved are those that are engaged in maintaining focus in novel and demanding tasks which includes both challenging WM tasks, and those assessing fluid intelligence, (Clark, Lawlor-Savage & Goghari, 2017). Clark et al., (2017), selected a challenging dual n-back WM task which required adult participants to respond to randomised aural and visual spatial computer-generated repetitions from increasing numbers of exposures; therefore, the participants experienced verbal and visual stimuli. In addition, they were required to complete a word versus non-word lexical recognition task. They concluded that the neural network supporting WM activity is domain general. This perspective is shared by Shipstead et al., (2016) who have proposed an alternative top down model of problem solving cognitive activity in which 'maintenance' of and 'disengagement' from key information are key functions, and in which working memory and fluid intelligence are not named factors. They propose that WM is not limited by capacity but rather by attentional control and/or deliberately forgetting outdated or superfluous information; another way of expressing interference (Oberauer, Farrell, Jarrold & Lewandowsky, 2016). Regardless of the different perspectives, the consensus of opinion among researchers is that there is a strong correlation between measures of WM capacity and measures of fluid intelligence.

Some researchers believe that WM capacity is a stronger predictor of academic attainment than fluid intelligence, (Alloway & Alloway, 2009). Similarly, Cain, Oakhill and Bryant (2004), found that WM rather than IQ predicted academic attainment in a longitudinal study of KS2 children in the UK. WM capacity has been found to correlate with reading comprehension (Swanson, 2011; Cain, 2006; Pham & Hassan, 2014) Pham and Hassan (2014) found correlations between domain specific WM capacity and comprehension with verbal WM being a strong predictor of both reading comprehension and fluency. They also report correlations between visual spatial WM capacity and reading comprehension most strongly but also to a lesser degree with fluency. Conversely a study of German third graders found no correlation between visual spatial working memory performance and literacy skills but found a correlation between verbal working memory and reading and phonological memory and spelling (Brandenburg, Klesczewski, Fischbach, Schudardt, Buttner et al., 2015).

Text writing is an extremely complex activity which relies on a number of cognitive abilities during its completion. At many points during the process, analysis of already written content is considered, refined, compared to information held within long term memory whilst simultaneously paying regard to spelling, grammatical rules, semantics, audience and genre conventions (Flower & Hayes, 1981). WM capacity supports organisation of thought throughout (Swanson & Berninger, 1996). Learners with Attention Deficit Hyperactivity Disorder (ADHD) tend to have weaker WM capacity than neurotypical peers (Alderson, Kasper, Hudec, Patross, 2013; Martinussen, Hayden, Hogg-Johnson & Tannock, 2005). Individuals with ADHD experience a number of academically based difficulties; writing is one such challenging task for learners with WM deficits as they can forget what they want to say within a sentence, or how the current sentence was going to fit into a paragraph, and lose connecting ideas, (Gathercole, Lamont & Alloway, 2006). Additionally, in a writing exercise where organisation and generation of thought is removed from the task and text is merely dictated, researchers found that pupils with ADHD, who are recognised to have weaker WM capacity, produced more spelling errors than the control group. Furthermore, when placed under the stress of retaining preloaded phonological information, and thereby engaging verbal working memory, whilst scribing a second piece of dictated text similar in design and complexity as the first, the group with ADHD made a significantly greater amount of spelling errors than they had in the first piece of text writing and a greater percentage of errors than the control group (Re, Mirandola, Esposito & Capodieci, 2014).

WM capacity has also been linked with mathematical attainment (Bull, Espy & Weibe, 2008; Witt, 2011). A meta-analysis of 110 studies researching WM and mathematics found correlations between verbal, numerical and visual spatial WM and problem solving when the problem to be solved is presented in a sentence, and calculations involving whole numbers. Geometry was found to have the weakest correlation with WM out of all mathematical skills reviewed (Peng, Namkung, Barnes & Sun 2015). Mathematical calculations rely heavily upon keeping information in mind whilst manipulating it, creating the next step and/or extracting further number facts from long term memory. Witt (2011) asserts that mathematical and memory gains were made as a result of a 6-week intervention in WM training.

2.6.6 Working memory interventions

Intervention for learners with WM capacity deficits can take the form of differentiation. A learner with a deficit in WM expressed as a standard score <85, would be given 25% additional time in public examinations of any subject where receiving extra time has been the "normal way of working" (JCQ 2017) and the need is evident. In the classroom differentiation could take the form of:

- additional time to complete tasks
- reduced workload/reduced academic timetable
- alternative ways to express knowledge and understanding e.g. being allowed to use bullet points rather than paragraphs
- teacher to check understanding
- notes given before lesson/lecture
- peer support (Gathercole & Alloway, 2008)

It appears that a general consensus concerning the efficacy of WM training does not currently exist. Witt (2011) asserts that WM training is effective in improving academic ability in mathematics. In his study of thirty-eight 9 and 10-year olds, children were allocated to intervention and control groups on a matched pair basis. The intervention group received 6 weeks of memory training, the schedule is listed in Table 1.

Table 1. *Memory training schedule, (Witt, 2011).*

	Task
Week 1	List of to be remembered objects.
Week 2	Practicing rehearsal

Week 3	Backward span practice plus an updating task
Week 4	Metacognitive instruction on coping with interference/distraction
Week 5	Counting recall practice task
Week 6	Backwards digit span

At the end of the intervention pupils in the intervention group performed significantly better at the backward span task and in mathematical calculations in the form of addition of one figure and two figure sums with and without regrouping due to column totals greater than 9. Such calculations require the support of working memory as interim totals need to be held in mind whilst further calculations are executed (Chinn, 2016). However, standardised attainment tests in mathematics were not used to determine baseline abilities nor to measure any degree of improvement. Conversely St. Clair-Thompson, Stevens, Hunt and Bolder, (2010) did use standardised tests of maths, reading and arithmetic immediately after memory training intervention for primary aged pupils with a mean age of 6.11. Neither immediately after training nor at a point 5 months later did they observe any improvements in performance on standardised tests. However, they did observe significant improvements on unstandardised tests for following instructions and mental calculations, in addition to digit, block and listening recall tasks. A meta-analysis conducted by Melby-Lervag and Hulme (2013) on studies examining the efficacy of WM training in typically developing children and adults found no evidence of sustained generalisation to academic attainment.

Cognitive effort has been found by some researchers to depend upon temperament of the subject. Studer-Leithi, Bauer and Perrig (2016) found that transfer of memory training to academic attainment in second grade pupils was correlated with results from effortful control. Those pupils who scored high effortful control, transferred gains made in working memory training to crystallised intelligence, maths and reading, whereas those with poor self-regulation did not. However, transfer gains were not maintained over time. Chavalier, (2018) suggests that low performance may also occur due to children's unwillingness to engage in cognitive effort rather than an intrinsic deficit in cognitive processing; that children with a growth mindset may be able to better engage in the task. It is clear that behavioural traits may also exert an influence on cognitive performance.

2.7 Emerging questions

Regardless of the possible effects of behavioural traits on cognition, it is clear from research that individual differences in cognitive abilities are well studied and documented and their influence upon academic attainment well established. What is not clear is how well researched cognitive deficits and effective intervention are in the secondary aged population; researchers have expressed concerns about the dearth of RCTs and studies which target the UK secondary aged population (Paul & Clarke 2016; Snowling & Hulme 2011). Further analysis of this demographic would add to the current body of research and perhaps identify area(s) of concern in order to inform interventions.

In the UK at the moment we appear to have moved away from research led pedagogical practice. In addition to the shortcomings in the Rose review (Rose, 2006) outlined above, one further example is the new spelling and grammar assessment for KS2 pupils (Gov.uk, 2018). This move appears to be largely opinion led. In their 2005 paper, Andrews, et al., (2006) conducted two systematic reviews of studies which examined whether the teaching of grammar had an effect on the quality of written output of 5-16-year olds. They concluded that it did not nor had any such study found that explicit instruction in grammar had improved literacy performance over the last 100 years. However, grammar instruction now forms a significant part of the current assessment and therefore curriculum for year six pupils. In her review of the new Spelling, punctuation and Grammar (SPaG) focus, Stafford, (2016) concludes that some teachers think it is effective and others not. Not all teachers are convinced that this grammatical knowledge is transferred by the pupils to their own writing. This review cites only 5 references in the body of the text: two are produced by the Department for Education (who Stafford works for) and three are papers on bilingualism, no conflicts of interest were reported. There is no empirical data; only teacher opinion is sought. The English Association (EA, 2017) of teachers and lecturers express concern that: “the tests which 11-year olds are required to take continue to have a negative effect in the English curriculum, particularly in Year 6 where ‘teaching to the test’ inevitably takes place”.

Furthermore, learning and retaining definitions and meanings of terms such as fronted adverbials and subordinate clauses can be difficult for pupils with speech and language impairments and other learning difficulties. When learning these terms by rote offers no real advantage to the pupil, it is important to ensure that practice is embedded in research and not opinion.

Specialist teachers use techniques which have been developed from peer reviewed research such as: sentence combining (Connors, 2000; Saddler, Asoro & Behforooz, 2008); metacogntion (Kellogg & Whiteford 2009) deliberate practice (Ericsson 2008 Kellogg & Whiteford, 2009;); collaborative writing (Grief 2007) to support struggling writers. It is important that we ascertain the nature and scale of cognitive deficits experienced by school aged children so that effective intervention can be targeted to ameliorate symptoms of difficulties in the classroom.

This study aims to add to the existing body of knowledge on the relationship between academic attainment and cognitive processing in KS3 pupil in a UK mainstream secondary school. The hope is that the analysis of data will add to existing understanding of pupil difficulties in an academic setting and help to inform and target effective intervention. After consideration of existing research, it was determined that this study would specifically examine the relationship between:

i. Memory modality and literacy attainment
ii. Memory type and literacy attainment
iii. Processing speed and attainment
iv. Reaction times and attainment
v. The incidence of deficit found in this study's cohort

A decision was made on the basis of current research discussed here not to assess phonological awareness, see Discussion chapter for rationale.

Chapter Three

3. Method

This study investigated the presence and incidence of memory and processing speed deficits within a KS3 mainstream school population. Participants were assessed using a number of different assessment tools in order to gather the necessary data. This chapter will describe the study design in detail.

3.1 Participants

All Key Stage 3 pupils from a secondary school in South Gloucestershire were included in the study. Parental consent was gained from all parents/carers through the use of an opt out letter. The design had been given approval from the University of Bristol Faculty of Science Human Research Ethics Committee.

25 year 8 and 27 year 9 pupils took part in the initial part of the study and undertook the Ravens assessment – these 52 pupils formed the entirety of the Key Stage 3 cohort in the school at that time.

3.2 Assessment

All assessments were carried out by the researcher who at the time was also the school SENDCo and specialist dyslexia teacher/assessor. The researcher holds a Post Graduate Diploma in Dyslexia and Literacy and had a current assessment practicing certificate at the time of assessment. The researcher is registered on the SASC website and as such is approved to carry out SpLD, Disabled Student Allowance (DSA) assessments for Higher Education students and exam access assessments for GCSE and A levels.

Some of the tests that were carried out are accepted by the JCQ as evidence for extra time in exams. Where students appeared to qualify, teachers were informed and pupils were then allowed additional time as a reasonable adjustment in the classroom and in their end of term/year subject assessments. This enables a body of evidence of need to be built to support applications for access arrangements in public exams should the extra time prove to be beneficial. Parents were also informed if their children achieved standard scores that could later qualify them for additional time in public exams.

3.3 Tasks

With the exception of the Raven assessment which was administered as a group task, all tasks were carried out on a 1:1 basis. The AWMA and the reaction time tests were computer based; all other tests were delivered by the researcher.

3.3.1 Raven Standard Progressive Matrices (Raven 1990)

The Raven's Standard Progressive Matrices is a test of non-verbal reasoning which can be administered in a group setting. It is a 60-item assessment which, while progressing in difficulty, requires the participant to apply themselves to abstract visual/spatial problem solving.

It is multiple choice in design and possesses a significant positive correlation with Wechsler Adult Intelligence Scale-Revised Full-Scale IQs (WAIS-R FSIQ) (O'Leary, Rusch & Guastello 1991). The Ravens SPM is used internationally and test-retest reliability varies dependent upon population. For this study raw scores for each pupil were noted, i.e. the exact number of correct items made. Reliability coefficient is .88

3.3.2 Automated Working Memory Assessment (AWMA) (Alloway, 2007)

This is a battery of standardised, normed, automated tests of memory for participants aged from 4 to 22.11 years which are administered on a 1:1 basis. The AWMA Short Form assessments were selected for this study; The Long Form consists of 12 separate memory assessments and is recommended for more detailed assessments.

The full battery of 12 assessments consists of 3 tasks in each of the following categories: verbal short-term memory, verbal working memory, visual spatial short-term memory and visual spatial working memory. The short form battery consists of: Digit Recall, Listening Recall, Dot Matrix and Spatial Recall; the short form will be used in this study. These four assessments are described in greater detail below. There is a practice trial for all tests and for all tests the discontinue rule is three incorrect responses within a block of test trials. There are two test trials for each task.

Digit recall (verbal short-term memory) – this is a simple test of forward span in which the participant listens to a string of numbers delivered by the program, which increase in length and is required to repeat them back in the same order that they were delivered. The practice trials consist of 1,2, and three single digit numbers. The test begins with 1 number being delivered, this increases up to a block of 9 numbers in total. The standard score achieved in this test will provide the verbal STM dependent variable to be evaluated in this study. The reported reliability coefficient for this test is .89.

Listening recall (verbal working memory) – the participant listens to a sentence delivered by the program and has to determine if it is true or false and then at the end of the sentence is required (see table 2) to recall the final word delivered. For example:

Table 2. *Example items in a similar format to the Raven Listening Recall (verbal WM) assessment.*

Trial	Response	Recall
Apples swim in the sea	False	'sea, sing'
Birds can sing	True	

NB sentences are similar to those delivered by the program.

The practice trials are for 1 and 2 sentences with the test trial starting with 1 sentence and increasing to 6. From two or more sentences onwards, the final words are repeated after the last sentence has been declared true or false. This test will provide the verbal working memory dependent variable expressed as a standard score to be evaluated in this study. The reliability coefficient for this test is .88.

Dot Matrix (visual spatial short-term memory) – the participant recalls the position of a red dot which can appear in any one of 16 squares on a 4x4 grid. The number of red dots increases from 1 to 9 (they appear one at a time and then disappear again) and

the participant points to the location(s) of the dots after the sequence has been shown.

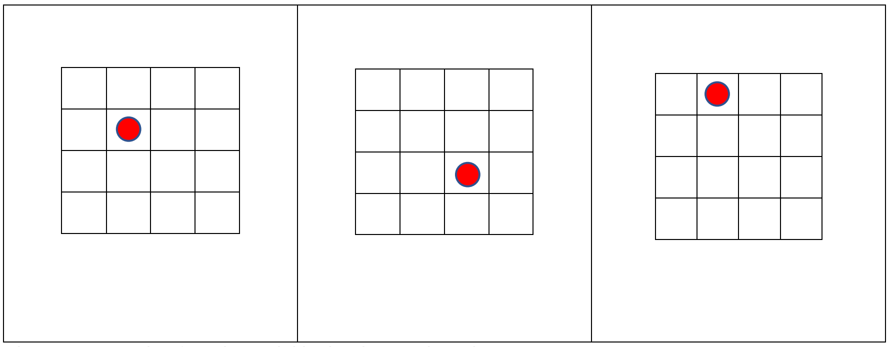

Figure 1. Example of a 3-item trial in the dot matrix task.

The red dot in the first grid would have disappeared by the time the one in the second grid appears and so on. This test will provide the visual spatial short term memory variable measured as a standard score to be evaluated in this study. The reliability coefficient for this test is .85.

Spatial recall (visual spatial working memory) - two shapes appear on the screen and the participant is required to state whether the orientation of the second shape is the same as or opposite to the first in terms or orientation – in other words, is it reversed. The participants are required to state ‘same’ or ‘opposite’. The second shape has a dot (which is coloured red in the AWMA) and may be rotated. The participant is required to state whether the shapes are same or opposite for an increasing number of shapes up to 7 in total and then recall in the correct order the positions of the red dots on the screen by indicating against an array of dots presented on the screen. This test will provide the visual spatial working memory dependent variable as a standard score to be evaluated in this study. The reliability coefficient of this test is .79.

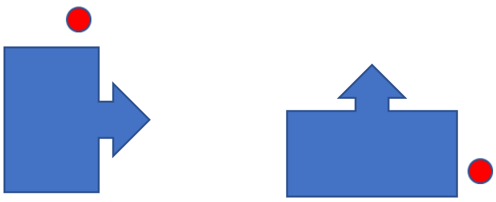

Figure 2. A similar task to those presented in the AWMA visual spatial working memory task. This is an example of an ‘opposite’ shape.

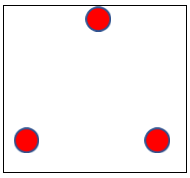

Figure 3. Participant indicates position of dot by pointing at one of the three presented. In the Figure 2 example, the participant would point to the bottom right dot.

Test reliability was measured on 128 randomly selected participants in the 4.10 to 22.5 age range by the test developer.

3.3.3 University of Bristol Reaction Time Tests.

These reaction time (RT) tests were developed by the University of Bristol Experimental Psychology department.

Phonological Reaction Time Tests

Participants were advised that they would be hearing a list of nonsense words – the concept of a nonsense word was explained and the same examples (not appearing in the test) were given to each participant, including some that began with the target phoneme and some that did not. Participants were then presented with a list of 20 non-words and were asked to discriminate between those that had an initial phoneme <k> and those that began with any other phoneme. Upon detection of a non-word beginning with a <k>, participants were required to press a particular button identified with a green button on the keyboard as quickly as possible, if the non-word started with any initial phoneme other than <k>, they were required to press a red button. The z on the keyboard had a red sticker on it and participants reacted using their left hand, the forward slash, '/' key, had the green sticker for which the right hand was used. Both buttons were situated 2 keys in from the edge of the keyboard on the lower row, above the space bar. Each participant was given 4 practice words before starting the test.

Examples of similar non-words to those presented in the test are: koj, sith, kak, kal, nibe, reet, kaysh

Two trials of 20 words were presented and RTs in milliseconds were recorded by the program. Median scores in milliseconds for each list of non-words were then calculated and recorded as the RT for each trial. In addition, the program recorded the number of correct responses made by each participant. This test will provide the phonological RT variable for this study.

Visual Reaction Time Tests

In this test, participants were required to discriminate between two photographs, each showing a different species of frog; similar frogs to those in the RT test are shown in Figure 4. Participants were shown the frogs before the test started and were given 4 practice trials before the test commenced.

Figure 4. Similar visual stimuli to those presented in the visual reaction time test.

The correct responses are shown in table x below. As for the phonological test, there was a 500 ms interval between each participant's response and the presentation of the next item. If the frog on the left (frog 1) was presented, the participant pressed the red button; for the frog on the right (frog 2) they pressed the green button.

Table 3. Example of a possible pattern of frog presentations

Trial1	2	2	2	1	2	1
Trial 2	2	1	2	2	1	1

3.3.4 Comprehensive Test of Phonological Processing – 2nd Edition (CTOPP2) (Wagner, Torgesen, Rashotte, Pearson, 2013)

The alphanumeric assessments of the Rapid Symbolic Naming subtests within the CTOPP2 were used in this research; these core subtests are intended for participants between 4 and 24 years of age. The tasks require the participant to retrieve information from long term memory accurately and at speed. The rapid naming tasks form one part of the phonological processing battery within the CTOPP2. These tasks will provide the rapid naming dependent variables as standard scores which will be evaluated in this study; they also provide a composite score, which is the result of the summed rapid naming subtest scaled scores, expressed as a standard score.

Rapid Digit Naming subtest – here, the participants are invited to practice saying a string of 6 digits: 4,8,7,2,5,3 and then for the actual test are asked to read a page of 36 of these particular digits, well-spaced and randomly sequenced on an A4 page. This task will measure the rapid digit naming dependent variable.

Rapid Letter Naming - this process is then repeated for the Rapid Letter Naming subtest. Here the letters a,t,s,k,c, and n are presented in lower case as a practice; a page of 36 of these randomly sequenced letters is then presented and the participant is timed reading them as fast as they can. This task provides the raid letter naming dependent variable for this study.

Using an alternate form method across the 4-17+ age range, immediate mean reliability coefficients calculated are .85 and .87 for Letters and Digits respectively and .92 for the Composite which is the converted result of the summed scaled scores of the rapid digit and rapid letter naming subtests.

Symbol Digit Modalities Test (SDMT) (Smith, 2010)

The SDMT was first published in 1973 and was devised as a screening tool to measure cerebral dysfunction in children and adults (SASC, 2016). The data collected can be converted to standard scores. The SDMT provides supplementary evidence for exam access arrangements. It is a symbol search task which requires the participant to select a number from a key to represent a series of randomly presented geometric designs, see Figure 5 below.

>	∞	(	<	≠	+	)	˩
1	2	3	4	5	6	7	8

(	<	˩	≠	+	∞	>	+	˩	≠	)	>	∞	C	≠

Figure 5. An example key and sample response line, similar to SDMT, with initial 10 items as practice examples.

The test consists of 7 further lines of 15 items in addition to the line which is similar to the one shown above. The raw score is calculated from the number of correct responses made, i.e. the correct corresponding number placed in the box below each symbol, within a 90 second time limit. The test has written and verbal response sheets built in to the design – only the written was used in this study. The difficulty with this test is that it is difficult to interpret which process it is measuring: reaction time, clerical speed, visual processing, visual working memory etc. (SASC, 2018). Kiely, Butterworth, Watson and Wooden (2014, p. 767) assert that the test is “underpinned by attention, perceptual speed, motor speed and visual scanning”. However, it is useful as a supplementary assessment when considered in relation to other test scores. Reliability coefficients were obtained by test-retest of 80 adults; test-retest correlation for the written SDMT was .80. Reliability of this test is brought into question due to its age (SASC, 2016) as it has not been norm referenced since it was published in 1973, however it has been found to correlate highly (r = .91) with the Digit Symbol subtest of the Weschler Adult Intelligence Scale (WAIS) (Morgan & Wheelock, 1992) and also correlates well (r = .62) with the Weschler Intelligence Scale for Children – Revised (WISC-R) (Lewandowski, 1984 cited in Morgan & Wheelock 1992). Raw scores obtained are converted to standard scores to the SDMT dependent variable for this study.

3.3.5 Literacy Attainment Tasks

Single Word Spelling Test (SWST) (Sacre and Masterson, 2000) GL Assessment

The Single Word Spelling Test (SWST) consists of a number of spelling lists which are graded in difficulty according to age. The participants in this research were administered Test F which is suitable for learners between the ages of 10.04 and 12.02 years which would have been appropriate for all participants in this study upon entry to the school in year 7. The test is administered to a group and takes approximately 30 minutes to deliver. Each word is presented orally, then delivered again within a sentence and then repeated once more as a single word. Scores can be converted to standard score or reading age, for this study the standard score was used for the spelling dependent variable. The reliability coefficient for Test F is .96.

National Foundation for Educational Research (NFER) Reading Test (1992)

This test was taken by all participants on entry to the secondary school in year 7. In this group reading assessment participants are presented with 20 sentences with missing words and they have to choose the correct word to insert from a given list. The sentences increase in complexity as the test progresses. The test simultaneously tests for word reading and sentence comprehension. Scores are recorded as standard scores and provide the reading dependent variable for this study. Internal consistency is .87

All tasks delivered by the assessor have a practice element before administration so that the participant is aware of what is required.

3.4 Procedure

The study took the form of a matched group design. The Raven's Progressive Matrices (Raven, 1990) was administered in groups to classes during their personal development lessons. This fitted with the curriculum requirements to understand about oneself as a learner. Participants were then divided into two groups depending upon their Key Stage 2 literacy grade. Individuals in the lower group were matched with a counterpart in the higher group based on the same or very similar Ravens raw score, ensuring at least one entire literacy grade difference existed between them. This matching process resulted in 2 groups of n=21 students: the lower performing literacy group was comprised of 11 boys and 10 girls; age in months M = 159.14, SD = 8.28; the higher performing group was comprised of 9 boys and 12 girls; age in month M = 159.19, SD = 6.194.

Pupils take Standard Achievement Tests (SATs) at the end of their primary education in year 6. The pupils in this study would have taken their SATs in 2013 and 2014. The 2013 the literacy SATs comprised of a reading paper which carried approximately 10 pages of illustrated text concerning wolves: fiction and non-fiction and an answer booklet in which 29 questions about the text were posed. Unless given extra time, pupils were allocated 15 minutes to read the text and 45 minutes to answer the questions. In addition to the reading paper, pupils would have completed a 20-word spelling test for which there was no set time limit although the paper states that 15 minutes should suffice and a grammar, punctuation and spelling paper which carried 46 questions to be answered within 45 minutes. Results from all three papers would have contributed to the final KS2 literacy grade awarded.

The grades achieved are supplied via an information management system to the pupils' secondary school of choice. In the vast majority of cases, the grades range from 2 to 5 with each numerical grade being subdivided from a-c, with 'a' being the highest; consequently, a grade of 5c is higher than a 4a. Each sub level is allocated a nominal numerical grade so that the School Information Management System (SIMS) can calculate grade predictions for year 11 based on KS2 performance. It is the progress made between KS2 and KS4 that determines a school's performance results, (Gov.uk, 2018). The grade 3a has been allocated the nominal figure 23, 4c = 25, 4b = 27 and so on.

In year 7 pupils are assessed for spelling and reading abilities; these have been added as standardised scores to the anonymised data.

Once allocated to either the lower or higher literacy groups, a number of assessments were carried out on a 1:1 basis. For these assessments, pupils came out of their personal development lessons to take part in the research. This is a non-examined subject and the assessor/researcher generally used personal development or PE for assessment for exam access in the school as a whole. This therefore fitted with the day-to-day practice in the school.

The assessments took place in the researcher's office and took approximately one hour to complete. All students appeared to be at ease as all were familiar with the researcher. The AWMA assessments took place on a laptop, with the pupils responding to each item as required with the researcher facilitating. They were presented with the verbal short-term memory (digit recall) subtest first followed by verbal working memory, visual short-term memory and visual/spatial working memory.

Next, the Reaction Time tests were administered; the phonological assessment was followed by the visual.

The CTOPP2 rapid naming battery of tests was then administered by the assessor with the pupils reading the above letters and digits as quickly as they could. The timings were noted. The written version of the SDMT was administered last with pupils transposing as many symbols to digits by hand as they were able within a given time limit.

3.5 Statistical methods

All scores (recorded as variables as either standard scores or reaction times in milliseconds) will be entered into SPSS as a data set. Analyses of variance in SPSS will be performed to establish if main effects and interactions exist. T-tests and bivariate and partial correlations between variables will also be examined.

Chapter Four

4. Results

Assessment results were examined by group for normal distribution using analysis of skewness and kurtosis by calculating if z scores (skewness and kurtosis/SE) lie between -1.96 - +1.96 (Cramer & Howitt, 2004). In addition, a Shapiro-Wilk Test of normality ($p>.05$) and a visual inspection of their histograms, normal Q-Q plots and box plots were conducted. Table 1 shows that all test scores were approximately normal with the exception of AWMA Visual Spatial Working memory for the higher literacy group (HLG), SWST for the lower literacy group (LLG) and AWMA STM Dot Matrix for the HLG. Existence or otherwise of outliers was determined by calculation of the difference between the first and third quartiles and multiplying it by a factor as established by Tukey (1977) in his outlier labelling rule with the value of 'g' increased from 1.5 to 2.2 as recommended by Hoaglin and Iglewicz (1987) for the sample size of this particular study. One outlier was found in the HLG AWMA WM Spatial Recall results and was removed – data were then normal. Initial descriptive statistics and normality z scores are presented in Table 4 for all task scores excluding the RT battery of assessments.

4.1 Sample characteristics and homogeneity of variance

Table 5 shows descriptive statistics for the battery of RT time tests. These results are not normally distributed and results for both literacy groups contain many outliers.

The assumption of homogeneity of variance was tested and satisfied by Levene's *F* test on each of the independent variables with the exception of: NFER reading score, $F(40)$ = 4.192, p = .047. equal variance not assumed, $F(33.788)$; Phonological RT test 1 $F(40)$ = 4.108 p = 0.49; equal variance not assumed, $F(28.602)$ Visual RT test 2 $F(40)$ = 4.229, = p = 0.46. equal variance not assumed, $F(24.738)$.

Table 4. *Initial Descriptive Statistics including Skew Kurtosis and Shapiro Wilk Scores for Attainment, Processing Speed and Memory Scores.*

	Mean	SD	Skewness Z score	Kurtosis Z score	Shapiro-Wilk
Raven's Raw Score lower	43.57	6.345	-1.072	0.472	.625
Raven's Raw score higher	42.85	5.706	-1.761	0.887	.199
NFER standard score lower	91.10	6.906	0.104	1.150	.394
NFER standard score higher	103.05	10.071	0.295	0.545	.954
SWST standard score lower	89.24	11.099	1.276	-0.990	.018
SWST standard score higher	106.20	9.053	0.735	0.513	.557
Age standard score lower	99.95	17.201	1.361	0.267	.246
Age standard score higher	100.28	13.151	0.519	-0.373	.541
AWMA STM Digit recall standard score lower	94.07	11.494	0.966	-0.504	.233
AWMA STM Digit recall standard score higher	101.11	10.953	1.360	0.970	.019
AWMA VWM Listening Recall standard score lower	98.01	15.214	-0.625	-0.069	.869
AWMA VWM Listening Recall standard score higher	104.33	16.315	0.597	-0.807	.469
AWMA VWM Listening Recall Processing standard score lower	97.49	13.059	-0.032	-0.303	.781
AWMA VWM Listening Recall Processing standard score higher	104.02	16.855	1.190	-0.291	.191
AWMA VS STM dot matrix standard score lower	102.09	17.642	-0.521	-0.963	.142
AWMA VS STM dot matrix standard score higher	103.18	14.503	0.916	-0.771	.324
AWMA VS WM Spatial recall standard score lower	111.16	15.491	0.489	-0.887	.337
AWMA VS WM Spatial recall standard score higher minus outlier case 42*	109.08	11.862	-0.900	0.651	.721
AWMA VS WM Processing standard score Processing lower	108.61	16.254	-0.238	-1.369	.940
AWMA VS WM Processing standard score higher	104.02	16.856	1.750	0.848	.630
SDMT standard score lower	100.62	16.639	0.241	0.162	.750
SDMT standard score higher	108.19	12.805	0.337	-0.918	.510
CTOPP2 RAN Digits standard score lower	91.14	12.627	-2.032	0.747	.028
CTOPP2 RAN Digits standard score higher	103.00	11.521	-0.964	0.455	.717
CTOPP2 RAN Letters standard score lower	84.29	14.167	0.086	0.833	.429
CTOPP2 RAN Letters standard score higher	101.05	11.99	0.401	0.367	.617
CTOPP2 RAN Composite standard score lower	85.43	15.039	1.002	-0.249	.218
CTOPP2 RAN Composite standard score higher	103.15	12.659	0.345	0.047	.655

Table 5. *Initial Descriptive Statistics including Skew, Kurtosis and Shapiro Wilk Scores for Reaction Time tests.*

	Mean	SD	Skewness Z score	Kurtosis Z score	Shapiro-Wilk
Phonological RT Test 1 ms lower	936.33	227.13	8.238	15.14	<.001
Phonological RT Test 1 ms higher	837.31	107.98	5.631	10.920	<.001
Phonological RT Test 2 ms lower	853.67	176.82	13.488	39.96	<.001
Phonological RT Test 2 ms higher	804.67	66.02	1.279	4.269	<.001
Phonological Test 1 number correct lower	18.00	2.45	-7.131	10.238	<.001
Phonological Test 1 number correct higher	18.90	2.45	-7.251	15.093	<.001
Phonological Test 2 number correct lower	18.14	3.79	-8.647	13.202	<.001
Phonological Test 2 number correct higher	18.81	2.81	-7.106	14.916	<.001
Visual RT Test 1 ms lower	532.33	263.41	14.438	43.294	<.001
Visual RT Test 1 ms higher	478.89	71.01	3.369	2.756	<.001
Visual RT Test 2 ms lower	516.55	156.46	8.277	14.483	<.001
Visual RT Test 2 ms higher	482.17	71.01	-4.134	5.360	<.001
Visual Test 1 number correct lower	18.05	2.33	-6.504	10.537	<.001
Visual Test 1 number correct higher	18.90	1.48	3.022	3.995	<.001
Visual Test 2 number correct lower	18.62	2.40	-10.548	26.961	<.001
Visual Test 2 number correct higher	19.00	1.09	-2.517	1.602	<.001

4.2 Grouping rationale

Students were matched for Ravens raw score and then allocated to one of two literacy groups (higher or lower) dependent upon KS2 SATs data for literacy. A differential of 3 sub grade levels between each pair was required – see method for more detailed description. An independent t-test was performed to ensure that the Ravens match was non-significant and that there was sufficient difference between the two groups in terms of achievement. The Ravens raw score between the two literacy groups was not significant, $t(40) = 0.177$, $p = .860$, the mean difference in literacy score between the groups was significant, $t(40) = -8.683$, $p < .001$.

Additionally age differences between the two groups were not statistically significant, $t(40) = -0.021$, $p = .983$.

4.3 Verbal and visual short term and working memory assessments.

The AWMA program provides automated standard scores for all subtests. For the working memory tests, it also supplies a processing score; this score relates to the participants ability to process the information presented with no regard to memory ability – see method for further details. In both the verbal and visual modalities, the working memory processing standard scores are highly correlated with the working memory standard scores. Participation in working memory processing is terminated when the cut off criteria are reached for the working memory tasks, thereby preventing further progress in processing that is independent of memory function. Because it is difficult to separate these two sets of dependent variables in terms of separate function and because they are so highly correlated, there is little value in examining both working memory and working memory processing in this results section. A bivariate correlation analysis in SPSS was performed and Pearson Correlation for AWMA verbal working memory, listening recall and listening recall processing was statistically significant, $r = .977$, n = 42, $p < .001$, as was the Pearson Correlation for visual/spatial working memory, spatial recall, and spatial recall processing, $r = .964$, n = 42, $p < .001$.

Table 6 shows descriptive statistics for verbal and visual short term and working memory assessments by Literacy Group (Lower or Higher).

Table 6. *Initial Descriptive Statistics for Memory Assessments by Group*

	Literacy Group			
	Lower		Higher	
Variable	M	SD	M	SD
AWMA verbal short-term memory – Digit Recall	94.07	11.49	101.11	10.95
AWMA verbal working memory – Listening Recall	98.01	15.21	104.33	16.32
AWMA Visual/Spatial short-term memory – Dot Matrix	102.10	17.64	103.18	14.50
AWMA Visual/Spatial working memory – Spatial Recall	111.16	15.49	109.08	11.86

For the following analysis it should be noted that a significant Shapiro-Wilk normality score was calculated at .018 for AWMA verbal short-term memory digit recall (see Table 4 above). Z scores for skewness and kurtosis are within the acceptable range and so further correction to the data has not been made. Additionally, an outlier was found among the AWMA Visual/spatial working memory data set and has been removed. As a result, for the higher literacy group n=20 and for the lower one n=21. The case has been excluded for the analysis of assessments of memory alone.

A 2 (modality: verbal/visual) x 2 (memory type: short-term/working memory) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the standard scores achieved for each of the 4 assessments of memory completed by the participants.

The analysis showed significant main effects of modality, $F(1,39) = 11.920$, $p = .001$, $MSE = 2007.976$, $\eta_p^2 = .234$, and of memory type, $F(1,39) = 10.644$, $p = .002$, $MSE = 1254.123$, $\eta_p^2 = .214$. The between subjects effect of literacy group was not significant, $F(1,39) = 0.875$, $p = .355$, $MSE = 391.043$, $\eta_p^2 = .022$. The main effect of modality reflected superior performance in the visual modality than in the verbal modality for both groups, similarly, for the main effect of memory type, superior performance is seen in working memory, see Table 6, Figure 6.

The Memory Type x Literacy Group interaction was not significant $F(1,39) = 0.330$, $p = .569$, $MSE = 38.938$, $\eta_p^2 = .008$, and neither was the Memory type x Modality interaction, $F(1,39) = 1.641$, $p = .208$, $MSE = 155.972$, $\eta_p^2 = .040$. The Modality x Literacy Group interaction approached significance, $F(1,39) = 3.131$),
$p = .085$, $MSE = 527.450$, $\eta_p^2 = .074$, the Memory Type x Modality x Literacy Group interaction was not significant, $F(1,39) = 0.160$, $p = .692$, $MSE = 15.173$, $\eta_p^2 = .004$. ~~between subjects effect of group was not significant, F(1,39) = 0.875, p = .355, MSE =~~

Although the Modality x Literacy Group interaction was not significant at the 5% level, because it was close to significant, a further analysis of the variance was conducted by running a repeated measures ANOVA after splitting the data by literacy group and examining the main effect of modality within both groups separately. For the Lower Literacy Group, the analysis showed a significant main effect of modality, $F(1,20) = 21.157$, $p < .001$, $MSE = 2354.263$, $\eta_p^2 = .514$. For the Higher Literacy Group, the analysis showed a non-significant main effect of modality, $F(1,19) = 1.019$, $p = .326$, $MSE = 232.903$, $\eta_p^2 = .051$.

A corresponding pair of ANOVAs were performed to determine the effect of literacy group on both verbal and visual modalities. For verbal memory the analysis showed a significant between subjects effect of literacy group, $F(1,40) = 4.337$, $p = .044$, $MSE = 1219.048$, $\eta_p^2 = .098$. For visual memory there was a non-significant between subjects effect of literacy group, $F(1,39) = 0.015$, $p = .904$, $MSE = 5.093$, $\eta_p^2 < .001$, see Figure 6.

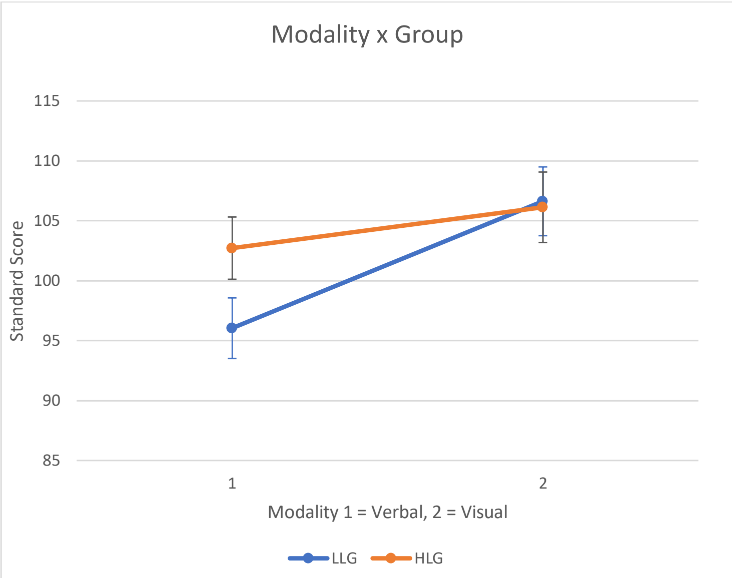

Figure 6. Lower and higher literacy group performance by modality, with standard error bars.

An independent samples *t* test was performed on the 4 AWMA subtest results. None of the differences between the mean of the two groups were significant at subtest level: AWMA verbal STM, $t(1,39) = -2.007$, $p = .052$; AMWA verbal WM $t(1,39) = -1.282$, $p = .208$; AWMA visual STM, $t(1,39) = -0.214$, $p = .831$; AMWA visual WM, $t(1,39) = .481$, $p = .633$.

4.4 Speed of processing tasks

The results for CTOPP2 rapid naming tasks and SDMT written are presented below.

4.4.1

Table 7 presents the descriptive statistics for the CTOPP2 rapid naming subtest scores.

Table 7. *Descriptive Statistics for Rapid Naming Tasks by Literacy Group*

	Literacy Group			
	Lower		Higher	
Variable	M	SD	M	SD
CTOPP2 Rapid Digit Naming	91.14	12.63	103.00	11.52
CTOPP2 Rapid Letter Naming	84.29	14.17	101.05	11.99
CTOPP2 Rapid Naming Composite	85.43	15.04	103.15	12.66

A 2 (rapid naming: digits/letters) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the standard scores achieved for each of the 2 assessments of rapid naming completed by the participants.

The analysis showed significant main effects of rapid naming, $F(1,40) = 6.839$, $p = .013$, $MSE = 443.440$, $\eta_p^2 = .146$ but ~~not of~~the Rapid Naming x Literacy Group interaction was not significant, $F(1,40) = 1.657$, $p = .205$, $MSE = 107.440$, $\eta_p^2 = .040$. The between subjects effect of group was significant, $F(1,40) = 16.433$, $p < .001$, $MSE = 4102.012$, $\eta_p^2 = .291$, because of the lower scores achieved by the lower literacy group in both of the rapid naming tasks, with the mean score for naming letters being the lowest, see Figure 7.

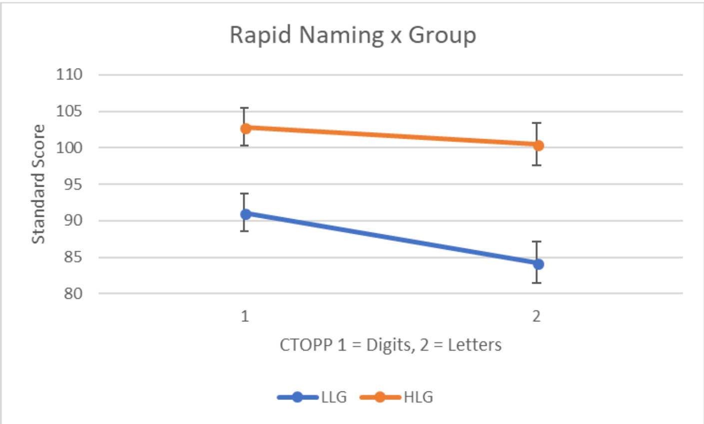

Figure 7. CTOPP2 Rapid naming: standard scores for digits and letters by lower and higher literacy groups, with standard error bars.

There was a significant difference in the scores for the lower literacy group for CTOPP2 rapid digit naming (*M* = 91.14, *SD* = 12.63) and the higher literacy group, (*M* = 103.00, *SD* = 11.52); *t*(40) = -3.174, *p* = .003. There was also a significant difference in the scores for the lower literacy group for CTOPP2 rapid letter naming (*M* = 84.29, *SD* = 14.17) and the higher literacy group, (*M* = 101.05, *SD* = 11.99); *t*(40) = -4.018, *p* < .001.

A one-way ANOVA was performed with the rapid naming composite by group as the composite of digit and letter naming is the most reliable rapid naming result in predicting reading fluency (Wagner et al, 2013). This showed a significant group difference *F*(1,40) = 16.536, *p* < .001, *MSE* = 3154.667, η_p^2 = .292, (see Figure 8) with the lower literacy group scoring significantly lower on the composite score than the higher literacy group.

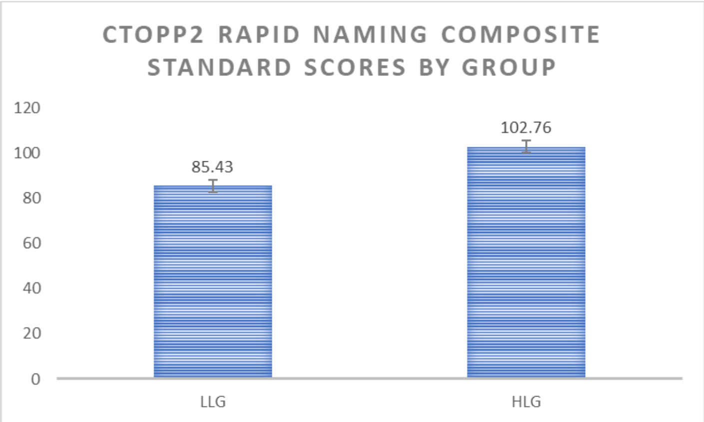

Figure 8. CTOPP2 rapid naming composite mean scores by group, with standard error bars.

~~Verbal Memory and Rapid Naming analysis of variance~~

4.4.1 SDMT written version

An independent samples *t* test was performed. This showed a non-significant difference in the scores for the lower literacy group for SDMT (M = 100.62, SD = 16.64) and the higher literacy group, (M = 108.19, SD = 12.81); $t(40) = -1.653$, $p = .106$.

~~**4.5**~~

Analysis of variance was undertaken to examine the interactions and effects of attainment and group. The initial descriptive statistics are represented in Table 8.

	Literacy Group			
	Lower		Higher	
Variable	M	SD	M	SD
NFER Reading	91.10	6.91	104.10	10.92
SWST Spelling	89.24	11.10	106.52	8.95

A 2 (attainment: reading/spelling) x 2 (group: lower/higher) mixed ANOVA was performed. There was no significant main effect~~s~~ of attainment, $F(1,40) = 0.036$, $p = .851$, $MSE = 1.714$, $\eta_p^2 = .001$, The between subjects effect of group was significant, $F(1,40) = 35.112$, $p < .001$, $MSE = 4815.429$, $\eta_p^2 = .467$, reflecting lower scores achieved in both tasks by the lower literacy group, see Figure 9. There was no significant interaction of Attainment x Group, $F(1,40) = 2.010$, $p = .164$, $MSE = 96.429$, $\eta_p^2 = .048$.

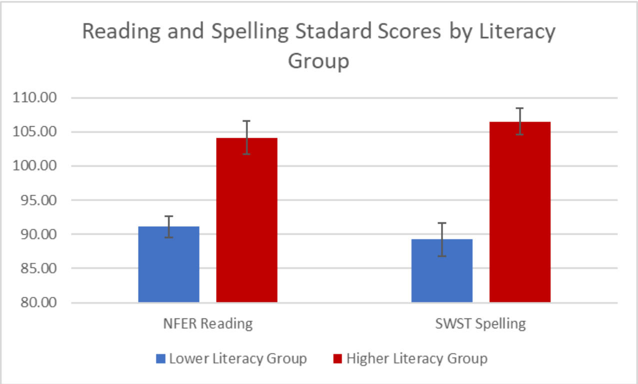

Figure 9. NFER Reading and SWST spelling mean standard scores by literacy group, with standard error bars.

An independent samples *t* test was performed on the NFER reading and SWST spelling assessment results. Mean score differences of both attainment measure were significant: NFER reading, $t(1,33.788) = -4.610$, $p < .001$; SWST spelling, $t(1,40) = -5.556$, $p < .001$.

4.364.6 Reaction Times and Error Analysis

The Reaction Time tests are not normally distributed; skewness and/or kurtosis exists for all variables, see Table 5. In addition, there are outliers present in each group and in each test.

Analysis of variance was performed to ascertain main effects and interactions between the RT tests and literacy group. Concerns about non-normality, see Table 5, should lead to caution in interpretation of results of this battery of assessments, it may be too ambitious to run analyses of variance that include modality, so analysis will be restricted to group interaction investigations.

Table 9. *Initial Descriptive Statistics for Reaction Time (RT) tasks.*

	Literacy Group			
	Lower		Higher	
Variable	M	SD	M	SD
Processing response time (ms)				
Phonological RT Test 1	936.33	227.13	837.31	107.98
Phonological RT Test 2	853.67	176.82	804.67	66.02
Visual Test RT 1	532.33	263.41	478.89	71.01
Visual Test RT 2	516.55	156.46	482.17	71.01
Correct responses (items correct)	M	SD	M	SD
Phonological Test 1	18.00	2.45	18.90	2.45
Phonological Test 2	18.14	3.79	18.81	2.81
Visual Test 1	18.05	2.33	18.90	1.48
Visual Test 2	18.62	2.40	19.00	1.09

A 2 (phonological RT: Test1/Test2) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the median times in ms achieved for each of the 2 assessments of phonological RT completed by the participants.

The analysis showed significant main effects of phonological RT, $F(1,40) = 15.599$, $p < .001$, $MSE = 69805.503$, $\eta_p^2 = .281$; ~~not of~~the Phonological RT x Literacy Group interaction was not significant, $F(1,40) = 2.936$, $p = .094$, $MSE = 13137.503$, $\eta_p^2 = .068$. The between subjects effect of group was not significant, $F(1,40) = 2.558$, $p = .118$, $MSE = 115033.003$, $\eta_p^2 = .060$.

A non-parametric Mann Whitney U test was performed to ascertain if there were significant differences between the two literacy groups for either test. The result for phonological test 1 was statistically significant, $U = 142$, $p = .048$, and for phonological test 2 it was not statistically significant, $U = 175$, $p = .252$. This result should be treated with caution however as the two phonological tests do not meet the assumption of similar distribution.

Similarly, a 2 (visual RT: Test1/Test2) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the median times in ms achieved for each of the 2 assessments of visual RT completed by the participants.

The analysis showed non-significant main effects of visual RT, $F(1,40) = .111$, $p = .741$, $MSE = 820.313$, $\eta_p^2 = .003$ and for the Visual RT x Literacy Group interaction, $F(1,40) = 0.259$, $p = .614$, $MSE = 1909.527$, $\eta_p^2 = .006$. The between subjects effect of group was not significant, $F(1,40) = 0.930$, $p = .341$, $MSE = 40502.146$, $\eta_p^2 = .023$.

In order to analyse the main effect and interaction upon the number of correct responses made by participants during the RT tests, two ANOVAs were performed. Firstly, a 2 (phonological correct responses: Test 1/Test 2) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the number of correct responses achieved for each of the 2 phonological RT tests completed by the participants.

The analysis showed non-significant main effects of phonological RT correct responses, $F(1,40) = 0.002$, $p = .966$, $MSE = 0.12$, $\eta_p^2 < .001$ and for the Phonological RT Correct Responses x Literacy Group interaction, $F(1,40) = 0.045$, $p = .833$, $MSE = 0.298$, $\eta_p^2 = .001$. The between subjects effect of group was not significant, $F(1,40) = 1.451$, $p = .235$, $MSE = 12.964$, $\eta_p^2 = .035$.

Secondly, a 2 (visual correct responses: Test 1/Test 2) x 2 (literacy group: lower/higher) mixed analysis of variance (ANOVA) was conducted on the number of correct responses achieved for each of the 2 assessments of visual RT completed by the participants.

The analysis showed non-significant main effects of visual RT correct responses, $F(1,40) = 1.886$, $p = .177$, $MSE = 2.333$, $\eta_p^2 = .045$ and for the Visual RT Correct Responses x Literacy Group interaction, $F(1,40) = 0.962$, $p = .332$, $MSE = 1.190$, $\eta_p^2 = .023$. The between subjects effect of group was not significant, $F(1,40) = 1.329$, $p = .256$, $MSE = 8.048$, $\eta_p^2 = .032$.

4.7 Correlation Results

In order to explore possible correlations between the variables, two tailed analyses were executed for each literacy group separately in SPSS using bivariate, correlation analyses, see Tables 10 and 12. Zero order correlations were calculated for Ravens raw score and age in months standard score only as these will be partialled out subsequently in order to examine the data without these two highly influencing variables

4.36.14.7.1 Lower literacy Group

Alpha values have been noted at both 0.05 and 0.01 significance levels.

Table 10. *Zero Order Correlations Table of Ravens Raw score and Age Variables for Lower Literacy Group. N = 21, df = 19.*

Zero Order		1	2	3	4	5	6	7	8	9	10	11	12	13	14	R	A
Ravens Raw Score	Corr	.116	.524	.622	.608	.646	.577	.361	.275	.155	.194	-.042	.337	-.074	.385	1.000	.368
	Sig	.616	.015	.003	.003	.002	.006	.108	.228	.502	.399	.855	.135	.751	.085	.	.100
Age in months	Corr	.102	.591	.534	.294	.530	.159	-.022	.214	.101	.150	-.313	.083	-.264	.065	.368	1.000
	Sig	.660	.005	.013	.196	.013	.492	.924	.351	.663	.518	.167	.719	.248	.781	.100	.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Corr = Correlation, sig = significance (2-tailed) R= Raven Raw Score, A= Age in months, 1= NFER reading, 2= SWST spelling 3 = AWMA Verbal STM, 4 = AWMA Verbal WM, 5 = AWMA Visual Spatial STM, 6 = AWMA Visual Spatial WM, 7 = SMDT Written, 8 = CTOPP2 Rapid Digit Naming, 9 = CTOPP2 Rapid Letter Naming, 10 = CTOPP2 RAN Composite, 11 = Phonological RT mean, 12 = Phonological RT number of correct responses mean, 13 = Visual RT mean, 14 = Visual number of correct responses mean.

Positive correlations at the .01 level were found between Ravens and: AWMA Verbal STM; Verbal WM, Visual Spatial STM and Visual spatial WM. There was also a positive correlation at the .01 level of significance between Age and SWST spelling.

Positive correlations at the 0.05 level are found between Ravens and: SWST spelling. Positive correlations were also found between Age and AWMA Verbal STM and AWMA Visual spatial STM at the .05 level of significance.

Partial correlations were run for each literacy group in order to determine the correlations between the test variables whilst controlling for age and for Ravens IQ, see Table 11.

Table 11. *Partial Correlations Table of Variables for Lower Literacy Group Controlled for Ravens raw Score and Age in Months. N = 21, df = 17.*

Controlled for Ravens and Age		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 NFER	Corr	1.000													
	Sig	.													
2 SWST	Corr	.526	1.000												
	Sig	.021	.												
3 Verbal STM	Corr	.509	.444	1.000											
	Sig	.026	.057	.											
4 Verbal WM	Corr	-.239	-.367	-.206	1.000										
	Sig	.323	.122	.399	.										
5 Visual Spatial STM	Corr	-.288	.066	-.465	.089	1.000									
	Sig	.231	.787	.045	.717	.									
6 Visual Spatial WM	Corr	-.131	-.236	-.133	.731	.246	1.000								
	Sig	.594	.330	.587	.000	.310	.								
7 SDMT	Corr	-.128	-.015	-.101	.273	.024	-.042	1.000							
	Sig	.600	.950	.680	.258	.923	.863	.							
8 RAN Digits	Corr	.277	.253	-.002	.027	.316	-.131	.460	1.000						
	Sig	.251	.295	.995	.911	.188	.593	.048	.						
9 RAN Letters	Corr	.572	.321	.432	-.161	-.137	-.265	.284	.615	1.000					
	Sig	.010	.180	.065	.511	.577	.273	.238	.005	.					
10 RAN Comp	Corr	.462	.307	.240	-.086	.080	-.236	.428	.856	.930	1.000				
	Sig	.046	.201	.322	.728	.746	.331	.068	.000	.000	.				
11 Phon RT Mean	Corr	-.406	-.273	-.204	-.101	-.003	-.024	-.089	-.560	-.350	-.469	1.000			
	Sig	.084	.258	.402	.681	.989	.924	.716	.013	.142	.043	.			
12 Phon Correct Mean	Corr	-.161	-.096	.014	.326	.142	.443	.111	-.307	-.098	-.185	.266	1.000		
	Sig	.509	.696	.954	.174	.562	.058	.652	.201	.690	.447	.271	.		
13 Visual RT Mean	Corr	-.312	-.243	-.011	-.036	-.038	.022	-.311	-.702	-.380	-.564	.872	.252	1.000	
	Sig	.194	.316	.963	.885	.876	.928	.195	.001	.108	.012	.000	.297	.	
14 Visual Correct Mean	Corr	-.417	-.124	-.073	.358	.197	.179	.292	-.082	-.040	-.033	.251	.514	.355	1.000
	Sig	.075	.612	.766	.132	.418	.463	.224	.739	.872	.892	.299	.024	.136	.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Corr = Correlation, sig = significance (2-tailed) R= Raven Raw Score, A= Age in months, 1= NFER reading, 2= SWST spelling 3 = AWMA Verbal STM, 4 = AWMA Verbal WM, 5 = AWMA Visual Spatial STM, 6 = AWMA Visual Spatial WM, 7 = SMDT Written, 8 = CTOPP2 Rapid Digit Naming, 9 = CTOPP2 Rapid Letter Naming, 10 = CTOPP2 RAN Composite, 11 = Phonological RT mean, 12 = Phonological RT number of correct responses mean, 13 = Visual RT mean, 14 = Visual number of correct responses mean. NB for the correlation means of both RT tests are used.

A partial correlation analysis was performed between the assessment variables when controlling for Ravens raw score and age in months. For the lower performing literacy group, positive correlations at the.01 level of statistical significance were found between: NFER reading and CTOPP2 rapid letter naming; AWMA verbal WM and AWMA visual spatial WM; CTOPP2 rapid digit naming and CTOPP2 rapid letter naming; CTOPP2 rapid letter naming and CTOPP2 rapid naming composite.

A negative correlation at the .01 level was found between: CTOPP2 rapid digit naming and visual RT mean due to RT scores in milliseconds being higher for the slower reacting participants. The negative correlation is to be expected.

At the .05 level of significance, positive correlations were found between: NFER reading and SWST spelling, AWMA verbal STM and CTOPP2 rapid naming composite; SDMT written and CTOPP2 rapid digit naming; phonological RT correct responses mean.

A negative correlation at the .05 level was found between: AWMA visual spatial STM and AWMA verbal STM; CTOPP2 rapid digit naming and phonological RT mean; CTOPP2 rapid letter naming and phonological RT mean; CTOPP2 rapid naming composite and both phonological RT mean and visual RT mean.

4.36.24.7.2 Higher Literacy Group

Table 12. *Zero Order Correlation Table of Ravens Raw score and Age Variables for Lower Literacy Group. N = 21, df = 18.*

Zero Order		1	2	3	4	5	6	7	8	9	10	11	12	13	14	R	A
Ravens Raw Score	Corr	.096	.227	.103	.041	.452	.510	-.098	-.364	-.250	-.352	-.277	.592	-.659	.435	1.000	.071
	Sig	.686	.337	.665	.863	.045	.022	.682	.114	.288	.127	.238	.006	.002	.055	.	.765
Age in months	Corr	.626	.219	.452	.565	.295	.183	.282	-.047	.020	.021	-.113	-.096	.034	-.103	.071	1.000
	Sig	.003	.354	.046	.009	.206	.440	.228	.843	.933	.931	.636	.689	.885	.667	.765	.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Corr = Correlation, sig = significance (2-tailed) R= Raven Raw Score, A= Age in months, 1= NFER reading, 2= SWST spelling 3 = AWMA Verbal STM, 4 = AWMA Verbal WM, 5 = AWMA Visual Spatial STM, 6 = AWMA Visual Spatial WM, 7 = SMDT Written, 8 = CTOPP2 Rapid Digit Naming, 9 = CTOPP2 Rapid Letter Naming, 10 = CTOPP2 RAN Composite, 11 = Phonological RT mean, 12 = Phonological RT number of correct responses mean, 13 = Visual RT mean, 14 = Visual number of correct responses mean. NB for the correlation means of both RT tests are used.

In the bivariate correlation analysis (see table 12), positive correlations at the .01 significance level were found between Ravens and: phonological RT correct responses mean and a negative correlation at this level with visual RT mean. Positive correlations at the .05 significance level are found with AWMA visual spatial STM and AWMA visual spatial WM AWMA Verbal STM.

Positive correlations at the 0.01 significance level are found between age in months and: NFER reading and AWMA verbal WM. Positive correlations were also found at the .05 significance level between age in months and AWMA Verbal STM.

Statistically significant positive correlations at the .01 level were found in the partial correlation between: CTOPP2 rapid digit naming and CTOPP2 rapid naming composite; CTOPP2 rapid letter naming and CTOPP2 rapid naming composite. Negative correlations at .01 level of statistical significance were found between CTOPP2 rapid letter naming and phonological RT mean and visual RT mean, (see table 13).

Additionally, statistically significant positive correlations at the .05 level were found in the partial correlation between: AWMA verbal STM and AWMA verbal WM; AWMA visual spatial STM and SDMT written; AWMA visual spatial WM and SDMT written; CTOPP2 rapid digit naming and CTOPP2 rapid letter naming. Negative correlations at this level of significance were found between AWMA verbal STM and visual RT correct responses mean.

Higher Literacy Group Partial Correlation Analysis

Table 13. *Partial Correlations Table of Variables for Higher Literacy Group. N* = 20, *df* = 16.

Controlled for Ravens and Age		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 NFER	Corr	1.000													
	Sig	.													
2 SWST	Corr	.515	1.000												
	Sig	.029	.												
3 Verbal STM	Corr	.045	.299	1.000											
	Sig	.860	.228	.											
4 Verbal WM	Corr	.069	-.041	.530	1.000										
	Sig	.785	.872	.024	.										
5 Visual Spatial STM	Corr	-.357	-.341	-.320	.119	1.000									
	Sig	.146	.166	.196	.639	.									
6 Visual Spatial WM	Corr	.090	.092	.072	.296	.457	1.000								
	Sig	.724	.718	.776	.232	.057	.								
7 SDMT	Corr	-.224	-.215	-.258	.363	.555	.527	1.000							
	Sig	.371	.392	.301	.138	.017	.025	.							
8 RAN Digits	Corr	-.130	-.317	.011	.375	.130	-.003	.489	1.000						
	Sig	.608	.199	.964	.125	.607	.992	.040	.						
9 RAN Letters	Corr	.012	.000	.076	.183	-.269	.026	.255	.502	1.000					
	Sig	.964	.999	.764	.467	.281	.917	.308	.034	.					
10 RAN Comp	Corr	-.056	-.159	.040	.311	-.100	.011	.433	.861	.869	1.000				
	Sig	.827	.529	.876	.209	.694	.964	.072	.000	.000	.				
11 Phon RT Mean	Corr	-.250	.006	-.051	-.164	.093	-.224	-.046	-.089	-.637	-.413	1.000			
	Sig	.316	.981	.842	.516	.712	.372	.858	.724	.004	.089	.			
12 Phon Correct Mean	Corr	.098	-.172	-.094	.198	.308	.445	.470	.288	-.069	.117	.235	1.000		
	Sig	.699	.495	.712	.431	.214	.065	.049	.247	.785	.643	.348	.		
13 Visual RT Mean	Corr	.380	-.166	.028	-.094	-.156	-.174	-.314	-.139	-.603	-.433	.331	.013	1.000	
	Sig	.120	.511	.913	.710	.536	.489	.205	.583	.008	.073	.180	.960	.	
14 Visual Correct Mean	Corr	-.018	-.391	-.557	-.108	.238	.018	.124	-.002	-.307	-.182	.462	.329	.265	1.000
	Sig	.944	.108	.016	.671	.341	.943	.623	.994	.216	.469	.053	.183	.288	.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.36.34.7.3 Partial correlation differences in significance between groups

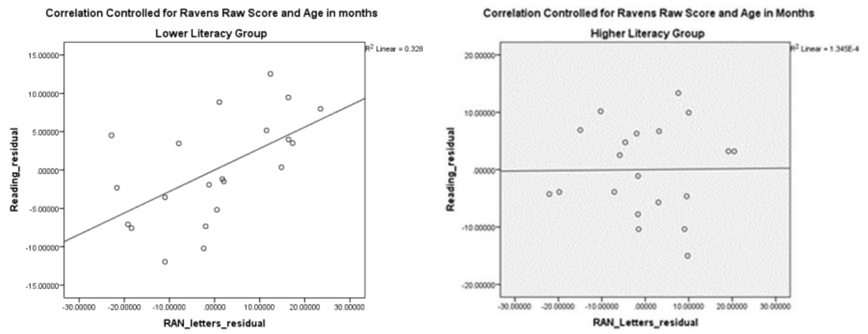

Figure 10. Scatter plots for higher and lower literacy groups illustrating comparative residuals correlations between CTOPP2 rapid letter naming and NFER reading dependent variables after controlling for Ravens Raw score and Age in Months.

Figure 10 shows the difference in correlation between the CTOPP2 rapid letter naming and NFER reading dependent variables; the partial correlation calculation was significant for the lower group, r = .572, p = *.010* and non-significant for the higher group, r = .012, p = .964. Calculating Fisher z to r reveals a non-significant difference between the two correlation results, z = 1.89, p = .059. All Fisher calculations carried out if this section are 2 tailed analyses.

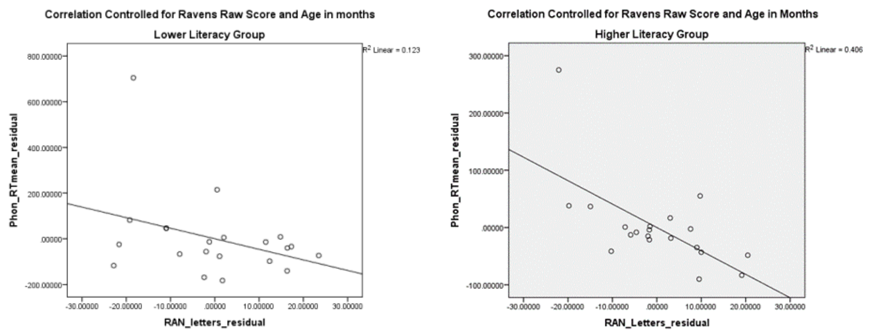

Figure 11. Scatter plots for higher and lower literacy groups illustrating comparative residuals correlations between CTOPP2 rapid letter naming and phonological RT mean variables after controlling for Ravens Raw score and Age in Months.

The partial correlation for the lower literacy group was not significant, r = -.350, p = .142, whereas the correlation for the higher group was significant, see Figure 11, r = -0.637, p = .004. Calculating Fisher z to r reveals a non-significant difference between the two correlation results, z = -1.15, p = .250.

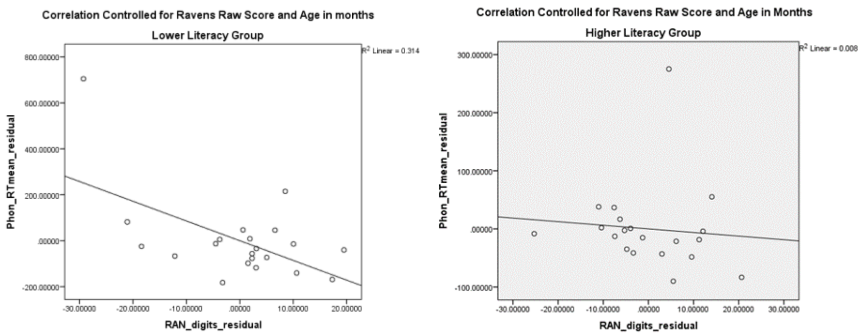

Figure 12. Scatter plots for higher and lower literacy groups illustrating comparative residuals correlations between CTOPP2 rapid digit naming and phonological RT mean variables after controlling for Ravens Raw score and Age in Months.

The partial correlation between phonological RT mean and CTOPP2 rapid digits naming (see Figure 12) was significant for the lower literacy group, r = -.560, p = .013 and not significant for the higher group, r = -.089, p = .724, this is the opposite finding for CTOPP2 rapid letter naming and phonological RT mean. Once more, calculating Fisher z to r reveals a non-significant difference between the two correlation results, z = -1.61, p = .107.

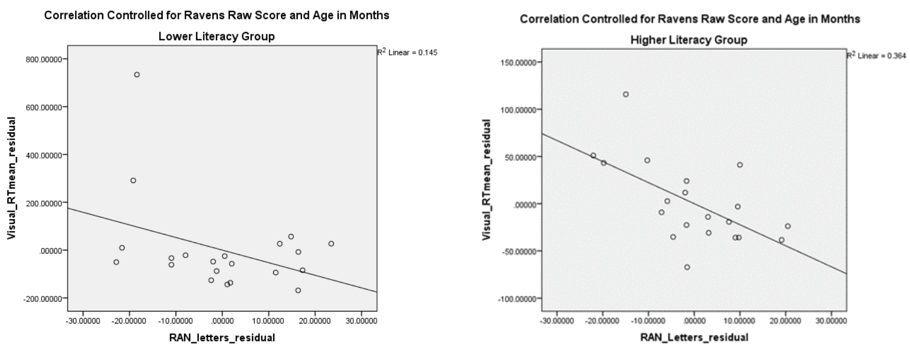

Figure 13. Scatter plots for higher and lower literacy groups illustrating comparative residuals correlations between CTOPP2 rapid letter naming and visual reaction time variables after controlling for Ravens Raw score and Age in Months.

The partial correlation between visual RT mean and CTOPP2 rapid letters naming (see Figure 13) was not significant for the lower literacy group, *r* = -.380, *p* = .108 and significant for the higher group, *r* = -.637, *p* = .004. Fisher *z* to *r* reveals a non-significant difference between the two correlation results, *z* = 1.04, *p* = .298.

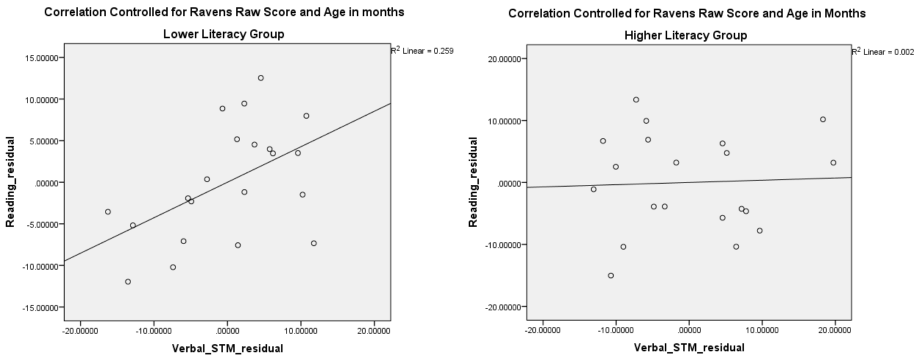

Figure 14. Scatter plots for higher and lower literacy groups illustrating comparative residuals correlations between NFER reading and verbal STM variables after controlling for Ravens Raw score and Age in Months.

The partial correlation between AWMA verbal STM and NFER reading was statistically significant for the lower literacy group, *r* = 509, *p* = .026 and not statistically significant for the higher group, *r* = .045, *p* = .960, see Figure 14. Fisher *z* to *r* reveals a non-significant difference between the two correlation results, *z* = 1.04, *p* = .298.

Chapter Five

5. Discussion

This chapter will revisit the above research questions and discuss and summarise the findings of the statistical results. Conclusions will be drawn and recommendations made for further research and practical pedagogical implications will be discussed.

5.1 Introduction

The overall aim of this study was to examine the relationship between literacy academic attainment (measured at the end of KS2) and elements of cognitive processing ability in KS3 pupils (ages 11-13) in a UK mainstream setting. The areas of cognitive processing explored were verbal and visual spatial STM and WM, rapid naming, visual/symbol search/clerical processing and reaction times.

The study aimed to investigate a number of questions:

1. Is the modality of memory pertinent in predicting academic attainment? The null hypothesis would be that there would not be statistically significant correlation between verbal or visual spatial memory and academic attainment.
2. Similarly, is there a statistically significant relationship between STM and/or WM and academic attainment in KS3 pupils in a mainstream setting in the UK?
3. Do processing speed abilities significantly impact upon academic attainment in KS3 pupils in the UK?
4. Do reaction times impact upon academic attainment in KS3 pupils in the UK?
5. What is the incidence of cognitive deficit based on standard scores which qualify for exam access arrangements within a KS3 sample population?

5.2 Statistical results discussion

This section will explore the results whilst considering the research questions above.

5.2.1 Research Question 1. Memory Modality and Academic Attainment.

The initial 2 x 3 analysis of variance (ANOVA) performed examined the effects of: modality i.e. verbal and/or visual spatial memory; memory type i.e., short term or working memory; lower or higher literacy group upon the dependent variable, in this case memory score, as measured by the two AWMA tasks (STM and WM) for each modality. The results revealed a significant main effect of modality upon memory scores.

Interactions between the factors and all were non-significant. However, the Modality x Literacy group interaction was close to significant and warranted further investigation. Examining the dependent variable scores for both groups individually for a main effect of modality, revealed significantly different results between the two groups. Further analysis which examined verbal and visual spatial memory specifically by group showed that there was a significant difference for verbal memory performance between the two groups but not for visual spatial memory performance. The lower literacy group achieved significantly lower performance on verbal memory tasks compared to the higher literacy group. There was no significant difference between groups for visual spatial memory performance, see Figure 6, although the lower literacy group mean result for visual working memory was slighter higher than the higher literacy group's mean result.

Therefore, in response to the first question of this study, the null hypothesis is rejected for verbal memory performance because the lower literacy group achieved significantly lower scores for verbal memory as measured by the AWMA verbal memory tasks than the higher literacy group achieved. However, the null hypothesis is accepted for visual spatial memory performance as measured by the AWMA, as there was no significant difference between the two groups on visual spatial memory tasks, (see notes in limitations below).

5.2.2 Research Question 2. Memory Type (STM/WM) and Academic Attainment

The above analysis of variance also revealed significant main effect for memory type; this was qualified by the fact that both groups achieved higher standard scores in working memory than short term memory (see Table 6). The Memory Type x Group interaction was not significant. There was no significant difference in memory type across the modalities between the groups.

Partial correlation analysis (controlled for Ravens raw score and the age of the participants) found a correlation between NFER reading and verbal STM alone at the .05 level in the lower literacy group; there were no significant correlations between any memory type and spelling for the lower group. Additionally, there were no significant correlations between any memory type or modality and either NFER reading or SWST spelling for the higher literacy group.

Therefore, we have evidence from the partial correlation between NFER reading and verbal STM that may be important but the difference between the two literacy groups on verbal STM is not strong enough to drive a significant interaction or reject the null hypothesis.

5.2.3 Research question 3. Processing Speed and Academic Attainment

The analysis of variance performed on CTOPP2 rapid naming task results by group, revealed a significant main effect of rapid naming and a non-significant result for the Rapid Naming x Group interaction. Additionally, a significant between-subjects effect of group was reported. The lower literacy group took significantly longer to name both digits and letters, subsequently the CTOPP2 rapid naming composite score achieved by the lower literacy group was significantly lower than that achieved by the higher group. Both literacy groups took longer to name letters than digits but there was a greater difference between the two tasks by the participants in the lower literacy group, see Figure 7. The difference between the two groups on CTOPP2 Composite score is statistically significant at the .001 level, see Figure 8.

Previous research has concluded that rapid naming abilities are closely correlated with reading fluency and ability. Partial correlation analyses, controlling for Ravens raw score and age standard score, conducted as part of this study show that for the lower literacy group, rapid letter naming is correlated with NFER reading at the .01 level of significance and the CTOPP2 composite correlates at roughly around .05. It is interesting to note that the rapid digit naming correlation with reading was non-significant, confirming lower level ability of the lower literacy group in letter naming. There were no significant correlations between either CTOPP2 rapid naming tasks and spelling however for either group. Correlation between CTOPP2 rapid letter naming and NFER reading in the higher literacy group is not significant, suggesting that for this study's cohort, rapid letter naming abilities impact upon NFER reading attainment of the lower group alone. In answering question 3 of this study we can reject the null hypothesis and conclude that processing speed performance, as measured by the CTOPP2 battery of assessments, is significantly lower in the lower achieving group and that rapid naming abilities, letter naming in particular, appear to impact upon academic attainment.

Recently, Toffalini, Marsura, Garcia & Cornoldi, (2018) asserted that the ability to manipulate visual phonological information efficiently is consistent with efficient STM ability. The fact that both rapid naming and verbal STM appear to be areas of relative difficulty for the lower literacy group is consistent with their research observations.

A second processing speed assessment was undertaken by the participants: the written version of the SDMT. This task is described as a symbol search task and clerical speed. The partial correlation analysis showed that there were no statistically significant correlations between SDMT and the lower literacy group attainment tasks (reading and spelling) but interestingly this task did correlate at the .05 level with CTOPP2 rapid digit naming, suggesting a shared difficulty in processing digits at speed regardless of the requirement to articulate them. This correlation was also present for the higher literacy group, again at the .05 level. An independent samples *t*-test showed that there was no significant difference in terms of processing speed as measured by the SDMT task between the two groups. The null hypothesis is rejected for processing speed as measured by the SDMT task.

5.2.4 Research Question 4. Phonological and visual reaction time tests

The reaction times of participants in each group were measured by computer-based assessments. There were two tests for both phonological RT and visual RT. In addition to measuring the RTs in milliseconds, the program recorded the number of correct responses made. These reaction time tasks are not norm referenced unlike all of the other tasks in this study; it is not meaningful to consider analyses of variance between different types of tests e.g. memory x RT.

Concerns about non-normality of the computerised RT tests led to caution in interpretation of results and consequently factor analysis was limited to the factor of test sessions (i.e. Test1/Test2) without modality being considered.

An ANOVA was performed on the two phonological RT tests x group; it found a significant main effect of phonological RT. The phonological reaction times were significantly different from each other from test 1 to test 2 with test 2 having a quicker median time, see Table 9. A Mann Whitney U test revealed statistically significant difference in median times between the groups for test 1 but not for test 2; there were 8 outliers across the groups in the first test. A very cautious interpretation of this might be that the lower literacy group participants benefited from the practice of the first trial. This cautious observation would be consistent with over learning and repetition intervention theories for learners with SPLD/Dyslexia (Bogaerts et al., 2015, Cochrane & Binns, 2015). Clearly though, we cannot make any conclusions from this one example and further studies would be needed before any conclusions can be drawn.

Further analyses of variance were performed upon the two visual RT tests by group, phonological RT tests items correct by group and visual RT tests items correct by group. There were no significant main effects, interactions or between groups effects in any of the results obtained.

It is difficult to conclude that the null hypothesis has been rejected with certainty due to the concerns about normality and significant results occurring in one trial out of the four. Further assessments of reaction times would be prudent.

The partial correlation controlled for Raven raw score and age showed a statistically significant correlation at the .01 level between phonological RT and CTOPP2 rapid letter naming variables in the higher literacy group and at the .05 level between phonological RT and CTOPP2 rapid digit naming variables in the lower literacy group. The partial correlation also found statistically significant correlations at the .01 level between visual RT and: CTOPP2 rapid letter naming in the higher literacy group; CTOPP2 rapid digit naming in the lower literacy group. Reaction time task results did not correlate with any other assessment results in this study. These tasks were both discrimination tasks, requiring a greater degree of information processing than a simple task would require. This may account for the correlation results described above. Further research examining the correlation between simple RT tasks and processing speed tasks, especially within and across domains might explore shared and discrete factors further.

5.2.5 Research Question 5. Incidence of cognitive deficit

12 participants achieved standard scores of below 85 in the rapid letter naming task; scores achieved would qualify them for extra time of 25% in exams. 2 of the 12 are in the

higher literacy group, the remaining 10 are lower level literacy achievers. 6 participants achieved standard scores below 85 in the verbal STM task; all low STM score participants are in the lower literacy group and all also lie in the below 85 standard score range for CTOPP rapid letter naming. Examining the results of cognitive areas shown to have a significant effect upon academic attainment, we can see that at least one processing speed deficit exists for 28.6% of participants in this study: 83% of these participants are found in the lower literacy group. This percentage cannot be extrapolated to the general population due to sample size and the fact that we removed some of the year group in order to create the matched pairs group design. Given that last year 15.7% of pupils were awarded 25% extra time in exams, (Gov.uk, 17) the percentage of pupils in this study who have at least one area of cognitive processing deficit, does suggest that further research to discover representative levels of cognitive deficit might be useful.

5.3 Research findings summary

In this section, conclusions from the results of this study are summarised in the light of previous research. Many differing viewpoints have been published over the years and the analyses outlined in this study neither prove nor disprove any existing theories but hopefully add some small detail to the already sizeable body of work.

A statistically significant difference between performance levels across the two modalities found in this study supports a domain specific model of memory (Oberauer et al., 2000), (although does not differentiate between processing and storage, or between STM or WM).

Analysis of the results of this study has shown that for the KS 3 participants who were assessed, verbal memory is of greater significance to academic achievement than visual memory. This finding goes someway to support Brandenburg et al's., (2015) finding that verbal working memory rather than visual working memory is more closely associated with literacy skills in terms of modality but not type and supports findings by Webster, Hall, Brown & Bolen (1996) that pupils with attention and learning difficulties experience more difficulty with auditory than visual recall.

Many researchers have found that academic attainment is influenced upon and/or correlates with WM (Cain, Oakhill & Bryant, 2004; Gathercole et al., 2016; Swanson & Jerman, 2006) However, in this study, statistically significant differences between the higher and lower achieving group were not found. Only verbal STM was found to correlate at a statistically significant level with the NFER reading test in the lower literacy group.

The lower literacy group achieved statistically significantly lower rapid naming scores than the higher group. In addition, rapid naming correlated with NFER reading for the lower group but not the higher group. These findings are consistent with previous research that rapid naming ability is a predictor of reading abilities, (Denkla & Rudel, 1975; Jones, Snowling & Moll, 2016; Kruk & Ruban, 2016).

The reaction time tests were not normally distributed and outliers existed in both groups, therefore any findings must be viewed with caution. A statistically significant difference was found between the two groups only in the phonological RT first test. The effect of practice may have improved the second test performance. There was as strong pattern of correlation between the RT tests and the CTOPP2 rapid naming tests. Differing theories exist to explain rapid naming as a predictor of reading ability, especially fluency (Kail et al., 1999; Jones, Snowling & Moll, 2016). Aroujo et al., (2011), found that the pause between items was the main contributory factor to slow rapid naming performance rather than articulation rates. Could this be a potential link to RT?

Finally, this study has identified that slightly over a quarter of the cohort of participants experience a deficit in at least one area of cognitive processing, the majority of these belonging to the lower literacy group.

5.4 Contribution to knowledge

The results of this study support a number of research studies which have concluded that certain elements of information processing, when required to be conducted at speed correlate with academic attainment (Wagner, Torgesesn Rashotte & Perason, 2013; Lee & Yoon, 2017). Rapid letter naming in particular, in this cohort of students, correlates strongly with both reading performance as measured by the NFER reading assessment and in academic achievement in literacy, evidenced by the statistically significant difference in means of rapid letter naming between the lower and higher literacy groups.

Additionally, the correlation between SDMT and rapid digit naming found in this study supports the assertion that the SDMT is to some degree a measure of processing speed despite some differing component elements e.g. naming speed for rapid naming (Jones, Snowling & Moll, 2016) versus clerical speed (among other processes cited by the authors) for the SDMT (Kiely, Butterworth, Watson & Wooden, 2014). Regardless of the importance of various processing elements of rapid naming in terms of contribution to speed, this study's correlation results support the theory that RAN is linked to processing speed, (Kruk & Roban, 2016).

The results that support the theory that memory is linked to attainment is partially supported by this study; certainly, a statistically significant difference in verbal memory between the two groups was found and verbal short-term memory in particular is correlated to academic achievement here. No statistically significant differences involving visual spatial memory were found between the two literacy groups.

For classroom practitioners, this study supports the view that deficits in certain processing speed abilities could be contributing to lower academic achievement. Educationalists and researchers alike are calling upon the Department of Education to be mindful of research findings when considering policy changes and increasing curriculum demands. If this study can contribute to this debate in some small way, the researcher would consider this to be a positive outcome.

5.5 Limitations of this study

5.5.1 Visual spatial assessments.

Unfortunately, the visual spatial STM (dot matrix) assessment in the AWMA depends upon the assessor recording the participant's responses correctly. The participant is shown a series of red dots which can be in any one of the cells presented in a 4 x 4 matrix. The task span maximum requires 9 separate consecutively presented dot locations to be recalled. After the final matrix has been presented, the participant is then required to point, in the right order, to all of the dot locations on an empty grid. Although the assessor can refer to a score card, which illustrates the correct location of each dot in the correct sequence, the score might be confounded by the assessor's ability to keep up with the speed of pointing whilst simultaneously checking against the score card and recording the response. Additionally, if the participant points to a location between two cells on the matrix, the assessor can ask them to point again, this distraction interference may cause loss of remembered items. Both of these factors may have led to some incorrect scores being recorded at the higher span levels. The fact that the participant's score was somewhat dependent on the ability of the researcher to process the response information quickly enough is of concern. This possible difficulty would have been limited to the higher scoring participants; unfortunately, there is no way of measuring any possible impact on accuracy.

A potentially similar difficulty arose during the visual spatial working memory part of the assessment. However, the maximum span for this task was 7 and so the possibility of making response scoring errors was reduced. The impact of any scoring error would have been to reduce performance scores for visual spatial working memory tasks.

There is scant literature documenting validity of the AWMA that has not been written by the author. An extensive search of papers detailing limitations and discussions around the difficulty of administering the AWMA has been undertaken with no findings of similar difficulties in administration identified. However, the AWMA-2 has been released and information included on the test author's website states:

> "Increase [d] user-friendliness: The AWMA-2 is now fully automated so both the administration and scoring are presented on the computer screen. This minimizes the risk of experimenter error both in the administration of the tests and in the scoring of the test". (tracyalloway, 2018)

This statement appears to acknowledge that difficulties in administration and scoring may have been present in the earlier version.

5.5.2 Listening recall assessments

The AWMA WM listening recall task may have caused some concerns in literal thinking pupils. The task asks them to repeat a sentence and then state if it was true or false. Certain participants struggled with 'flowers smell nice' for example, as not all do. Is this true or false? Sentences which caused a pause for consideration due to unforeseen complexity may well have caused a distraction and adversely affected attempts to memorise the item. How or if it affected scores, we cannot be certain but needs raising as a possible limitation of this element of the study.

5.5.3 Additional assessments

A decision not to include phonological awareness as part of this study was made despite the known correlation between academic attainment and phonological awareness, see literature review. The rationale was based on the fact that all participants in this study who entered the school with reading and or spelling standard score below 90 were enrolled on a literacy programme which provides structured, cumulative phonological and phonemic awareness tuition explicitly as an integral element. The Units of Sounds program used by the school was delivered by a dyslexia specialist and progress made, in standard scores in reading and spelling, was regularly monitored. In a study commissioned by Dyslexia Action and reported in Brookes "What works for children and young people with literacy difficulties- 5th edition," (2016). Effect size of 0.27 for reading ability was recorded over a 26-week period in n=118 year 7-9 pupils in a mainstream secondary school compared to a control group of n=89 who received no intervention. In an earlier study (n=32) effect sizes of 0.37-0.45 were found over a 20-week intervention period (Rack, 2009)

15 participants in this study would have received between 1 and 2 years additional Units of Sounds support at the time of assessment depending upon which academic year they were in. The researcher made the decision after reviewing the literature, that possible gains made in phonological awareness, through specific training, might confound any phonological awareness results and therefore did not include these specific assessments in this study.

5.5.4 Reaction Time Tests

The reaction time tests, developed by the University of Bristol Experimental Psychology School, are not norm referenced, unlike the other assessments used in this study. Therefore, they have been analysed as a separate group of tests and consequently no RT results have been analysed or correlations examined in relation to the results of norm referenced tests used to assess other cognitive processes.

The majority of the reaction time tests were not normally distributed and any analysis of results must be treated with caution, see Table 2.

The reaction time test response button colour choices may have affected performance of any participants with red/green colour blindness. This condition affects approximately 8 percent of males and 0.4 percent of females (Coleman, Ed. 2008). Although participants would have been advised which button was red and which was green, any colour-blind student would have additional load placed upon them by having to remember which button represented which reaction from its position as opposed to using a visual cue of colour. None of the participants were known to be colour blind but at approximately 8 percent of males this may have affected between 1 and 2 participants. Allread, Schreiner and Smithies, (2014) assert that too many research papers include red and green figures which people with colour blindness find difficult to interpret; perhaps in retrospect, the colour coding should have been differently applied to response requirements.

In addition, there may have been a Stroop effect and consequent reaction time delay caused by the green frog requiring a red button response. An unintentional, possibly incongruent colour naming element of this task may have delayed response times (Shitova, Roelofs, Schriefers, Bastiaansen & Schoffelen, 2016).

5.5.5 Sample size

The sample size of this study was restricted by the size of the school KS 3 cohort and the procedure of matching for Raven raw score and group allocation. The study would have benefited from a larger sample size; the correlations data may reflect a lack of power to find other interactions that may have become apparent with a larger sample size. Group sizes of 21 suggest a degree of caution should be taken to ensure that over-interpretation of correlation results does not happen. However, there are peer reviewed studies on cognitive deficits which have been reviewed as part of this thesis which have similar sample sizes, (Arujo et al., 2014; Suggate et al. ,2016; Barrouillet et al., 2007).

5.6 Directions for future research

Given the statistically significant correlations between rapid naming and reaction times, further research which examines shared components of rapid naming and reaction times might be beneficial. Previous studies have shown that interventions improve naming and reading fluency and that reaction times improve with rehearsal (Lee & Yoon, 2017; Der & Deary, 2009). Understanding exactly which cognitive processes drive the deficits and which are shared might prove useful in determining effective approaches for support.

Further research using memory assessments that facilitate accurate administration of the complete battery would be beneficial in order to confirm or otherwise the results presented in this study. Given the slower phonological RT, rapid naming and significantly lower verbal memory this study found in the lower literacy group, then a comparative study of cognitive load caused by verbal and visually presented items to be remembered might be useful, if this study's memory modality results are replicated, especially if such items represent realistic classroom demands.

In order to increase the opportunities to extend the influence of experimental psychology research findings more effectively into the classroom, research exploring the creation of effective assessments which closely replicate classroom demands may increase opportunities for the development of more classroom based RCTs thereby fulfilling Snowling & Hulme's, (2011, p.1) call for the 'virtuous circle' of research and effective interventions to be completed. An example of this could be pre-teaching of nonword definitions; how many repetitions are required before a learner with cognitive deficits retains a definition sufficiently well to apply it to a sentence? How effective are visual representations at reducing the cognitive load of remembering items? Students are required to rapidly develop technical lexicons in secondary school across all subjects; those with learning difficulties struggle to keep up. Research may result in the development of an effective classroom assessment for teachers rather than specialists, which would then in turn advise practitioners exactly how much pre-teaching would be effective. Non-word repetition, phonological assessments exist today, e.g. CTOPP2 (Wagner, Torgesen, Rashotte & Pearson, 2013); they can advise the degree of difficulty but not the level or nature of intervention required as a result.

Another example of an assessment might be one which measures how many instructions a learner can effectively process and then execute accurately. Does visual representation improve efficacy? Working memory measures currently used in the classroom give indications of level of weakness but not of exactly the nature and extent of support that would be beneficial for the learner. Extending some of the current experimental research to include measures of effective cognitive load reduction, memory retention, presentation of information utilising optimal modality based upon strategies that can be implemented in the classroom, to give a few examples, may serve to support effective pedagogical practice.

There is already much evidence in existence regarding the impact of cognitive deficits upon academic attainment. One important way forward would be to research the means to efficiently measure the cognitive profiles of all pupils so that incidence can be accurately measured and reasonable adjustments made at the earliest practical opportunity – the study would need to incorporate analysis of optimum age in its design.

This study, combined with rising levels of stress and anxiety apparent in learners of all ages in the UK, has highlighted the possible benefit that further studies on comorbidity of processing speed deficits and stress/anxiety in the classroom and indeed the lecture theatre might bring. Recent research has shown that alleviating stress in adults in the workplace, improves processing speed (Lacerda, Little & Kozasa, 2018). Speed of processing training has been found to be effective in older adults (Smith, Jones, Dotson & Wolinsky, 2018) and children (Mackey, Hill, Stone & Bunge, 2011); a research study measuring the impact of training on academic performance and measuring anxiety levels pre and post intervention might prove to be useful. The initial assessments would need to include a battery of assessments in differing modalities and cross-modal processing so that intervention could be accurately targeted.

Chapter Six

6. Conclusion

Researchers have been examining and identifying elements of cognitive processing which have an impact on academic attainment for many years. As our understanding of cognitive processing deficits and their implications increases so does our understanding of how this predicts academic attainment.

Evidence conclusions are mixed, some citing memory or processing speed deficits as the main factor, others find a number of factors at play. This research study has found verbal memory, processing speed and phonological RT may have an impact on academic attainment with approximately a quarter of participants assessed found to have at least one area of cognitive processing deficit.

From a pedagogical viewpoint, there is much to gain from greater understanding of how cognitive deficits impede progress in the classroom. At a time when so many young people are struggling with mental health issues whilst curriculum demands increase, it is important that educationalists continue to work closely with experimental psychologists. Important conclusions are drawn regularly from experimental research and a constant, collaborative and productive dialogue between researchers and practitioners is of paramount importance. The Education sector is required to change practice with each government term, sometimes on the basis of opinion and not fact (Haydn, 2012; Smith 2017). A positive step forward might be to develop further the scientific community response, in partnership with those in education, to proposed policy changes as they are announced and before they occur, if such changes are likely to be detrimental to those learners with cognitive processing deficits/differences.

Given the incidence of cognitive deficit found in this study and others, assessment of the introduction of a more robust curriculum is recommended and any resultant impact upon cognitively vulnerable pupils' academic performance and mental health should be measured. What impact are the more robust GCSE requirements having on students with cognitive deficits? The new performance indicators do not allow alternative, more accessible qualifications such as Step Up to English or Functional Skills (DfE, 2018b) to contribute to performance tables and as a result many schools do not offer them to the less academically able students. Some students, not capable of GCSE level work in 8 different subjects (DfE, 2018b), may be being denied access to more suitable qualifications. Additionally, the government's GCSE retake strategy requires that all post 16 students who achieved grade 3 or lower at GCSE English Language and Maths, must retake these GCSEs at Further Education (FE) colleges (DfE, 2018c). FE colleges are calling for a change in policy to allow Functional Skills qualifications to be taken as an alternative to avoid the experience of repeated failure for many students; (ATL, 2017) of those who achieved a D grade (or equivalent) at their first attempt; only 18% of students who retake a D grade achieve a pass grade at resit (feweek.co.uk, 18; tes.com, 18). Taking a different qualification may reduce the experience of repeated failure.

The Education system in the UK may benefit from further research into how imposing, by default, the same requirements for qualifications on a large majority of students, regardless of ability or level of cognitive deficit, fits with the legislation embodied in the Equality Act (2010) and whether such a demand constitutes indirect discrimination against those who have a disability and as such a protected characteristic under the Act.

At a time when almost half of the exclusions from schools are of pupils with known special educational needs (Gov.uk, 2018) it is of paramount importance that education provision supports learning difficulties and that the exact nature and incidence of learning difficulty is identified.

7. References

Adders (2018, July). What is ADD/ADHD? Retrieved from URL http://www.adders.org/

Alderson, R. M., Kasper, L. J., Hudec, K. L., & Patros, C. H. G. (2013). Attention-Deficit/Hyperactivity Disorder (ADHD) and Working Memory in Adults: A Meta-Analytic Review. *Neuropsychology, 27*(3), 287-302. doi:10.1037/a0032371

Alloway, T.P. (2007). *Automated Working Memory Assessment (AWMA)*. London: Pearson Assessment.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the Predictive Roles of Working Memory and IQ in Academic Attainment. *Journal of Experimental Child Psychology, 106*(1), 20-29. doi:10.1016/j.jecp.2009.11.003

Allred, S. C., Schreiner, W. J., & Smithies, O. (2014). Colour blindness: still too many red-green figures. *Nature, 510*(7505), 340. doi:10.1038/510340e

Andrews, R., Torgerson, C., Beverton, S., Freeman, A., Locke, T., Low, G., . . . Zhu, D. (2006). The effect of grammar teaching on writing development. *British Educational Research Journal, 32*(1), 39-55. doi:10.1080/01411920500401997

AQA (2018, July). Retrieved from URL https://www.aqa.org.uk/subjects/mathematics/gcse/mathematics-8300/appendix-mathematical-formulae

Araujo, S., Pacheco, A., Faisca, L., Petersson, K. M., & Reis, A. (2010). Visual rapid naming and phonological abilities: Different subtypes in dyslexic children. *International Journal of Psychology, 45*(6), 443-452. doi:10.1080/00207594.2010.499949

Araujo, S., Reis, A., Petersson, K. M., & Faisca, L. (2015). Rapid Automatized Naming and Reading Performance: A Meta-Analysis. *Journal of Educational Psychology, 107*(3), 868-883. doi:10.1037/edu0000006

Association for Achievement and Improvement through Assessment, (n.d). What are the statutory requirements for assessment in Key Stages 3 and 4? Retrieved from URL https://www.aaia.org.uk/assessing-without-levels/what-are-the-statutory-requirements-for-assessment-in-key-stages-3-and-4/

ATL (2017) Post 16 resits for English and Maths. Retrieved from URL https://www.atl.org.uk/post-16-resits-maths-and-english

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. doi:10.1016/S1364-6613(00)01538-2

Barnett, A. L., Prunty, M., & Rosenblum, S. (2018). Development of the Handwriting Legibility Scale (HLS): A preliminary examination of Reliability and Validity. *Research in Developmental Disabilities, 72*, 240-247. doi:10.1016/j.ridd.2017.11.013

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time Constraints and Resource Sharing in Adults' Working Memory Spans. *Journal of Experimental Psychology: General, 133*(1), 83-100. doi:10.1037/0096-3445.133.1.83

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and Cognitive Load in Working Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(3), 570-585. doi:10.1037/0278-7393.33.3.570

Bayliss, D. M., Jarrold, C., Baddeley, A. D., & Gunn, D. M. (2005). The relationship between short-term memory and working memory: Complex span made simple? *Memory, 13*(3-4), 414-421. doi:10.1080/09658210344000332

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The Complexities of Complex Span: Explaining Individual Differences in Working Memory in Children and Adults. *Journal of Experimental Psychology: General, 132*(1), 71-92. doi:10.1037/0096-3445.132.1.71

Benner, G. J., Allor, J. H., & Mooney, P. (2008). An Investigation of the Academic Processing Speed of Students with Emotional and Behavioral Disorders Served in Public School Settings. *Education and Treatment of Children, 31*(3), 307-332.

Bernstein, S. E. (2009). Phonology, Decoding, and Lexical Compensation in Vowel Spelling Errors Made by Children with Dyslexia. *Reading and Writing: An Interdisciplinary Journal, 22*(3), 307-331. doi:10.1007/s11145-008-9116-z

Bjork, K. (2014). Effects of internalizing behaviors on processing speed and academic fluency. In S. Loe, J. Crank, G. Hall, W. Jones, & T. Raines (Eds.): ProQuest Dissertations Publishing.

Bogaerts, L., Szmalec, A., Hachmann, W. M., Page, M. P. A., & Duyck, W. (2015). Linking memory and language: evidence for a serial-order learning impairment in dyslexia. *RESEARCH IN DEVELOPMENTAL DISABILITIES*. doi:10.1016/j.ridd.2015.06.012

Bowers, J. S., & Bowers, P. N. (2017). Beyond Phonics: The Case for Teaching Children the Logic of the English Spelling System. Educational Psychologist, 52(2), 124-141. doi:10.1080/00461520.2017.1288571

Brandenburg, J., Klesczewski, J., Fischbach, A., Schuchardt, K., Büttner, G., & Hasselhorn, M. (2015). Working Memory in Children with Learning Disabilities in Reading versus Spelling: Searching for Overlapping and Specific Cognitive Factors. *Journal of Learning Disabilities, 48*(6), 622-634. doi:10.1177/0022219414521665

British Dyslexia Association, (2018, June). About the British Dyslexia Association. Background. Retrieved from URL https://www.bdadyslexia.org.uk/about

Brooks, G. (2016, March). What works for children and young people with literacy difficulties. Retrieved from URL http://www.interventionsforliteracy.org.uk/wp-content/uploads/2017/11/What-Works-5th-edition-Rev-Oct-2016.pdf

Bugden, S., & Ansari, D. (2016). Probing the Nature of Deficits in the "Approximate Number System" in Children with Persistent Developmental Dyscalculia. *Developmental Science, 19*(5), 817-833. doi:10.1111/desc.12324

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's Reading Comprehension Ability: Concurrent Prediction by Working Memory, Verbal Ability, and Component Skills. *Journal of Educational Psychology, 96*(1), 31-42. doi:10.1037/0022-0663.96.1.31

Case, R., Kurland, D. M., & Goldberg, J. (1982). OPERATIONAL EFFICIENCY AND THE GROWTH OF SHORT-TERM-MEMORY SPAN. *Journal of Experimental Child Psychology, 33*(3), 386-404. doi:10.1016/0022-0965(82)90054-6

Chevalier, N. (2018). Willing to Think Hard? The Subjective Value of Cognitive Effort in Children. *Child Development, 89*(4), 1283-1295. doi:10.1111/cdev.12805

Chinn, S.J., (2017). More Trouble with Maths: A Complete Manual to Identifying and Diagnosing Mathematical Difficulties (2nd Ed.). Oxon: Routledge.

Chung, K. K. H., Ho, C. S. H., Chan, D. W., Tsang, S.-M., & Lee, S.-H. (2011). Cognitive Skills and Literacy Performance of Chinese Adolescents with and without Dyslexia. *Reading and Writing: An Interdisciplinary Journal, 24*(7), 835-859. doi:10.1007/s11145-010-9227-1

Clark, C. M., Lawlor-Savage, L., & Goghari, V. M. (2017). Functional brain activation associated with working memory training and transfer. *Behavioural Brain Research, 334*, 34-49. doi:10.1016/j.bbr.2017.07.030

Colman, A. M. (2008). red-green colour-blindness. In: Oxford University Press.

Colman, A. M. (2015). simple reaction time n. In (4 ed.): Oxford University Press.

Connelly, V., Dockrell, J. E., Walter, K., & Critten, S. (2012). Predicting the Quality of Composition and Written Language Bursts From Oral Language, Spelling, and Handwriting Skills in Children With and Without Specific Language Impairment. *Written Communication, 29*(3), 278-302. doi:10.1177/0741088312451109

Connors, R. J. (2000). The Erasure of the Sentence. *College Composition and Communication, 52*(1), 96-128. doi:10.2307/358546

Conrad, N., & Levy, B. (2011). Training letter and orthographic pattern recognition in children with slow naming speed. *An Interdisciplinary Journal, 24*(1), 91-115. doi:10.1007/s11145-009-9202-x

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*(2), 163-183. doi:10.1016/s0160-2896(01)00096-4

Conway, A. R. A., Jarrold, C., Kane, M. J., Miyake, A., & Towse, J. N. (2012). *Variation in Working Memory*.

Cowan, R., Donlan, C., Shepherd, D.-L., Cole-Fletcher, R., Saxton, M., & Hurry, J. (2011). Basic Calculation Proficiency and Mathematics Achievement in Elementary School Children. *Journal of Educational Psychology, 103*(4), 786-803. doi:10.1037/a0024556

Cowan, N. (1999). An Embedded-Processes Model of Working Memory. In A. Miyake and P. Shah, ed., *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control,* 1st ed. Cambridge: Cambridge University Press, pp62-101.

Cramer, D. (2004). *The Sage dictionary of statistics : a practical resource for students in the social sciences / Duncan Cramer and Dennis Howitt*. London: London : SAGE.

Daneman, M., & Carpenter, P. A. (1980). INDIVIDUAL-DIFFERENCES IN WORKING MEMORY AND READING. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466. doi:10.1016/s0022-5371(80)90312-6

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 3*(4), 422-433. doi:10.3758/bf03214546

Davis, A. (2012). A Monstrous Regimen of Synthetic Phonics: Fantasies of Research-Based Teaching "Methods" versus Real Teaching. *Journal of Philosophy of Education, 46*(4), 560-573. doi:10.1111/j.1467-9752.2012.00879.x

Deary, I. J., Der, G., & Ford, G. (2001). Reaction times and intelligence differences: A population-based cohort study. *Intelligence, 29*(5), 389-399. doi:10.1016/S0160-2896(01)00062-9

Deary, I. J., & Ritchie, S. J. (2016). Processing speed differences between 70- and 83-year-olds matched on childhood IQ. *Intelligence, 55*, 28-33. doi:10.1016/j.intell.2016.01.002

Denckla, M. B., & Rudel, R. G. (1976). RAPID AUTOMATIZED NAMING (RAN) - DYSLEXIA DIFFERENTIATED FROM OTHER LEARNING-DISABILITIES. *Neuropsychologia, 14*(4), 471-479. doi:10.1016/0028-3932(76)90075-0

Department for Education, (October, 2013). Reforming the accountability system for secondary schools Government response to the February to May 2013 consultation on secondary school accountability. Retrieved from URL https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249893/Consultation_response_Secondary_School_Accountability_Consultation_14-Oct-13_v3.pdf Accessed 21/8/17

Department for Education d) (2013, September). The National Curriculum in England: Key stages 1 and 2 framework document. Retrieved from URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/425601/PRIMARY_national_curriculum.pdf

Department for Education a), (2014, 16th April). Assessment Principles. Retrieved from URL https://www.gov.uk/government/publications/assessment-principles-school-curriculum

Department for Education c), (2014, 11th June). Special educational needs and disability code of practice: 0 to 25 years Statutory guidance for organisations which work with and support children and young people who have special educational needs or disabilities. https://www.gov.uk/government/publications/send-code-of-practice-0-to-25

Department for Education b), (2014, 2nd December). National curriculum in England: secondary curriculum. The national curriculum secondary programmes of study and attainment targets for key stages 3 and 4. Retrieved from URL https://www.gov.uk/government/publications/national-curriculum-in-england-secondary-curriculum

Department for Education, (2018a, 28th June). Schools, pupils and their characteristics: January 2018. Retrieved from URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/719226/Schools_Pupils_and_their_Characteristics_2018_Main_Text.pdf

Department for Education, (2018b, January) Secondary Accountability Measures: A guide for maintained secondary schools, academies and free schools. Retrieved from URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/696998/Secondary_accountability-measures.pdf

Department for Education, (2018c, 1st February) Guidance:16 to 19 funding: maths and English condition of funding. Retrieved from URL https://www.gov.uk/guidance/16-to-19-funding-maths-and-english-condition-of-funding

Der, G., & Deary, I. (2009). Age and Sex Differences in Reaction Time in Adulthood: Results From the United Kingdom Health and Lifestyle Survey (vol 21, pg 62, 2006). *Psychol. Aging, 24*(1), 229-229. doi:10.1037/a0015515

Dockrell, J. E., Lindsay, G., & Palikara, O. (2011). Explaining the Academic Achievement at School Leaving for Pupils with a History of Language Impairment: Previous Academic Achievement and Literacy Skills. *Child Language Teaching and Therapy, 27*(2), 223-237. doi:10.1177/0265659011398671

Dovis, S., Oord, S., Wiers, R., & Prins, P. (2013). What Part of Working Memory is not Working in ADHD? Short-Term Memory, the Central Executive and Effects of Reinforcement. *An official publication of the International Society for Research in Child and Adolescent Psychopathology, 41*(6), 901-917. doi:10.1007/s10802-013-9729-9

Ehri, L. C., Nunes, S. R., Stahl, S. A., & Willows, D. M. (2001). Systematic Phonics Instruction Helps Students Learn to Read: Evidence from the National Reading Panel's Meta-Analysis. *Review of Educational Research, 71*(3), 393-447. doi:10.3102/00346543071003393

Ellis, S. (2007). Policy and Research: Lessons from the Clackmannanshire Synthetic Phonics Initiative. *Journal of Early Childhood Literacy, 7*(3), 281-297. doi:10.1177/1468798407083660

English Association, The, (2018). English in Education: Current National Issues. Retrieved from URL https://www2.le.ac.uk/offices/english-association/news-1/english-in-education-current-national-issues

Ericsson, K. A., & Kintsch, W. (1995). Long-Term Working Memory. *Psychological Review*, *102*(2), 211-245. doi:10.1037/0033-295X.102.2.211

Fatemeh, H., & Tahereh Sima, S. (2015). Phonological working memory and auditory processing speed in children with specific language impairment. *Audiology*, *23*(6), 32-44.

FE Week (2016, 11th September). GCSEs vs functional skills: which English and maths resits should your students take? Retrieved from URL https://feweek.co.uk/2016/09/11/gcses-vs-functional-skills-which-english-and-maths-resits-should-your-students-take/

Ferguson, A. N., & Bowey, J. A. (2005). Global processing speed as a mediator of developmental changes in children's auditory memory span. *Journal of Experimental Child Psychology, 91*(2), 89-112. doi:10.1016/j.jecp.2004.12.006

Flower, L., & Hayes, J. R. (1981). A Cognitive Process Theory of Writing. *College Composition and Communication, 32*(4), 365-387. doi:10.2307/356600

Fostick, L., & Revah, H. (2018). Dyslexia as a multi-deficit disorder: Working memory and auditory temporal processing. *Acta Psychologica, 183*, 19-28. doi:10.1016/j.actpsy.2017.12.010

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science, 7*(4), 237-241. doi:10.1111/j.1467-9280.1996.tb00366.x

Fuchs, L. S., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., . . . Fletcher, J. M. (2006). The Cognitive Correlates of Third-Grade Skill in Arithmetic, Algorithmic Computation, and Arithmetic Word Problems. *Journal of Educational Psychology, 98*(1), 29-43. doi:10.1037/0022-0663.98.1.29

García, J. R., & Cain, K. (2014). Decoding and Reading Comprehension: A Meta-Analysis to Identify Which Reader and Assessment Characteristics Influence the Strength of the Relationship in English. *Review of Educational Research*, *84*(1), 74-111. doi:10.3102/0034654313499616

Gathercole, S. E., Lamont, E., & Alloway, T. P. (2006). Working memory in the classroom. In S. Pickering (Ed.), Working memory and education (pp. 219–240). London: Elsevier

Gathercole, S. E., Woolgar, F., Kievit, R. A., Astle, D., Manly, T., Holmes, J., & Team, C. (2016). How Common are WM Deficits in Children with Difficulties in Reading and Mathematics? *Journal of Applied Research in Memory and Cognition*, *5*(4), 384-394.

Geertsen, S. S., Thomas, R., Larsen, M. N., Dahn, I. M., Andersen, J. N., Krause-Jensen, M., . . . Lundbye-Jensen, J. (2016). Motor Skills and Exercise Capacity Are Associated with Objective Measures of Cognitive Functions and Academic Performance in Preadolescent Children. *PloS one, 11*(8), e0161960. doi:10.1371/journal.pone.0161960

Georgiou, G. K., Papadopoulos, T. C., & Kaizer, E. L. (2014). Different RAN Components Relate to Reading at Different Points in Time. *Reading and Writing: An Interdisciplinary Journal*, *27*(8), 1379-1394. doi:10.1007/s11145-014-9496-1

Georgiou, G. K., Parrila, R., Cui, Y., & Papadopoulos, T. C. (2013). Why Is Rapid Automatized Naming Related to Reading? *Journal of Experimental Child Psychology, 115*(1), 218-225. doi:10.1016/j.jecp.2012.10.015

Georgiou, G. K., Tziraki, N., Manolitsis, G., & Fella, A. (2013). Is rapid automatized naming related to reading and mathematics for the same reason(s)? A follow-up study from kindergarten to Grade 1. *Journal of experimental child psychology, 115*(3), 481. doi:10.1016/j.jecp.2013.01.004

Gojak, L.M., (2012, 1sr November). Fluency: Simply fast and accurate? I think not!. Retrieved from URL https://www.nctm.org/News-and-Calendar/ Messages-from-the-President/Archive/Linda-M_-Gojak/Fluency_-Simply-Fast-and-Accurate_-I-Think-Not!/

González-Valenzuela, M.-J., & Martín-Ruiz, I. (2017). Effects on Reading of an Early Intervention Program for Children at Risk of Learning Difficulties. *Remedial and Special Education, 38*(2), 67-75. doi:10.1177/0741932516657652

Goswami, U. (2008). The Development of Reading across Languages. *Annals of the New York Academy of Sciences, 1145*(1), 1-12. doi:10.1196/annals.1416.018

Gov.uk, (2013, 27th February). Equality Act 2010: guidance. Information and guidance on the Equality Act 2010, including age discrimination and public sector Equality Duty. Retrieved from URL https://www.gov.uk/guidance/equality-act-2010-guidance#equalities-act-2010-legislation

Gov.uk, (2017, 30th November). Ofqual: Access Arrangements for GCSE and A Level 2016 to 2017 academic year. Retrieved from URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/663391/Access_arrangements_2017_-_report.pdf

Gov.uk, (2018, May). Key stage 2 tests: 2018 English grammar, punctuation and spelling test materials. Retrieved from URL https://www.gov.uk/government/publications/key-stage-2-tests-2018-english-grammar-punctuation-and-spelling-test-materials

Grief, S. (2007, 6th September). Effective Teaching and Learning: Development Project Report. Retrieved from URL dera.ioe.ac.uk/22289/1/doc_3767.pdf

Grimley, M., & Banner, G. (2008). Working Memory, Cognitive Style, and Behavioural Predictors of GCSE Exam Success. *Educational Psychology, 28*(3), 341-351. doi:10.1080/01443410701635058

Haigh, S. M., Walsh, J. A., Mazefsky, C. A., Minshew, N. J., & Eack, S. M. (2018). Processing Speed is Impaired in Adults with Autism Spectrum Disorder, and Relates to Social Communication Abilities. *Journal of autism and developmental disorders, 48*(8), 2653. doi:10.1007/s10803-018-3515-z

Hall, D., Jarrold, C., Towse, J. N., & Zarandi, A. L. (2015). The Developmental Influence of Primary Memory Capacity on Working Memory and Academic Achievement. *Developmental Psychology, 51*(8), 1131-1147. doi:10.1037/a0039464

Hitch, G. J., Halliday, M. S., & Littler, J. E. (1989). Item identification time and rehearsal rate as predictors of memory span in children. *The Quarterly Journal of Experimental Psychology Section A, 41*(2), 321-337. doi:10.1080/14640748908402368

Hoaglin, D., & Iglewicz, B. (1987). Fine- Tuning Some Resistant Rules for Outlier Labeling. *Journal of the American Statistical Association, 82*(400), 1147-1149. doi:10.1080/01621459.1987.10478551

Hoaglin, D. C., Mosteller, F., & Tukey, J. W. (1983). *Understanding robust and exploratory data analysis / edited by David C. Hoaglin, Frederick Mosteller, John W. Tukey*. New York ; Chichester: New York ; Chichester : Wiley.

Hynds, J. (2007). Putting a spin on reading: The language of the Rose Review. In (Vol. 7, pp. 267-279).

Jarrold, C. (2017). The Mid-Career Award. *Quarterly journal of experimental psychology (2006), 70*(9), 1747. doi:10.1080/17470218.2016.1213869

Jarrold, C., & Bayliss, D. M. (2008). *Variation in Working Memory Due to Typical and Atypical Development*: Oxford University Press.

Jarrold, C., Mackett, N., & Hall, D. (2014). Individual differences in processing speed mediate a relationship between working memory and children's classroom behaviour. *Learning and Individual Differences, 30*, 92-97. doi:10.1016/j.lindif.2013.10.016

Joint Council for Qualifications, (2017, September). Adjustments for candidates with disabilities and learning difficulties. Access Arrangements and Reasonable Adjustments. Retrieved from URL https://www.jcq.org.uk/exams-office/access-arrangements-and-special-consideration/regulations-and-guidance/acce

Jones, A. (2011) *Dyslexia: Assessing the need for Access Arrangements during Examinations. A Practical Guide*. Evesham: Patoss

Jones, M. W., Obregon, M., Kelly, M. L., & Branigan, H. P. (2008). Elucidating the Component Processes Involved in Dyslexic and Non-Dyslexic Reading Fluency: An Eye-Tracking Study. *Cognition, 109*(3), 389-407. doi:10.1016/j.cognition.2008.10.005

Jones, M. W., Snowling, M. J., & Moll, K. (2015). What Automaticity Deficit? Activation of Lexical Information by Readers With Dyslexia in a Rapid Automatized Naming Stroop-Switch Task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. doi:10.1037/xlm0000186

Kail, R., Hall, L. K., & Caskey, B. J. (1999). Processing Speed, Exposure to Print, and Naming Speed. *Applied Psycholinguistics, 20*(2), 303-314. doi:10.1017/S0142716499002076

Kaplan, B. J., N. Wilson, B., Dewey, D., & Crawford, S. G. (1998). DCD may not be a discrete disorder. *Human Movement Science, 17*(4), 471-490. doi:10.1016/S0167-9457(98)00010-4

Katz, L. J., Brown, F. C., Roth, R. M., & Beers, S. R. (2011). Processing Speed and Working Memory Performance in Those with Both ADHD and a Reading Disorder Compared with Those with ADHD Alone. *Archives of Clinical Neuropsychology, 26*(5), 425-433. doi:10.1093/arclin/acr026

Kellogg, R. T., & Whiteford, A. P. (2009). Training Advanced Writing Skills: The Case for Deliberate Practice. *Educational Psychologist, 44*(4), 250-266. doi:10.1080/00461520903213600

Kibby, M. Y., & Long, C. J. (1997). The relationship between measures of phonological processing, word fluency and speech rate and measures of short-term verbal memory in children with dyslexia. In (Vol. 12, pp. 344-345).

Kiely, K. M., Butterworth, P., Watson, N., & Wooden, M. (2014). The Symbol Digit Modalities Test: Normative Data from a Large Nationally Representative Sample of Australians. *Archives of Clinical Neuropsychology, 29*(8), 767-775. doi:10.1093/arclin/acu055

Kim, J. S., Hemphill, L., Troyer, M., Thomson, J. M., Jones, S. M., Larusso, M. D., & Donovan, S. (2017). Engaging Struggling Adolescent Readers to Improve Reading Skills. *Reading Research Quarterly, 52*(3), 357-382. doi:10.1002/rrq.171

Koponen, T., Salmi, P., Torppa, M., Eklund, K., Aro, T., Aro, M., . . . Nurmi, J.-E. (2016). Counting and rapid naming predict the fluency of arithmetic and reading skills. *Contemporary Educational Psychology, 44-45*, 83-94. doi:10.1016/j.cedpsych.2016.02.004

Kruk, R. S., & Luther Ruban, C. (2016). Beyond Phonology: Visual Processes Predict Alphanumeric and Nonalphanumeric Rapid Naming in Poor Early Readers. *Journal of learning disabilities*.

Kudo, M. F., Lussier, C. M., & Swanson, H. L. (2015). Reading disabilities in children: A selective meta-analysis of the cognitive literature. *Research in Developmental Disabilities, 40*, 51-62. doi:10.1016/j.ridd.2015.01.002

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence, 14*(4), 389-433. doi:10.1016/S0160-2896(05)80012-1

Lacerda, S. S., Little, S. W., & Kozasa, E. H. (2018). A Stress Reduction Program Adapted for the Work Environment: A Randomized Controlled Trial With a Follow-Up. *Frontiers in Psychology, 9*(MAY). doi:10.3389/fpsyg.2018.00668

Lee, J., & Yoon, S. Y. (2017). The Effects of Repeated Reading on Reading Fluency for Students with Reading Disabilities: A Meta-Analysis. *Journal of Learning Disabilities, 50*(2), 213-224. doi:10.1177/0022219415605194

Lefstein, A., & Snell, J. (2011). Beyond a unitary conception of pedagogic pace: quantitative measurement and ethnographic experience. *British Educational Research Journal, 39*(1), 1-34. doi:10.1080/01411926.2011.623768

Leitao, S., Hogben, J., & Fletcher, J. (1997a). Phonological processing skills in speech and language impaired children. *European Journal of Disorders of Communication, 32*(2), 91-111.

Leitao, S., Hogben, J., & Fletcher, J. (1997b). Phonological processing skills in speech and language impaired children. *European Journal of Disorders of Communication, 32*(2), 91-111.

Mackey, A. P., Hill, S. S., Stone, S. I., & Bunge, S. A. (2011). Differential Effects of Reasoning and Speed Training in Children. *Developmental Science, 14*(3), 582-590. doi:10.1111/j.1467-7687.2010.01005.x

Magimairaj, B. M., & Montgomery, J. W. (2012). Children's verbal working memory: Relative importance of storage, general processing speed, and domain-general controlled attention. *Acta Psychologica, 140*(3), 196-207. doi:10.1016/j.actpsy.2012.05.004

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(4), 377-384. doi:10.1097/01.chi.0000153228.72591.73

McGeown, S. P., Johnston, R. S., & Medford, E. (2012). Reading Instruction Affects the Cognitive Skills Supporting Early Reading Development. *Learning and Individual Differences, 22*(3), 360-364. doi:10.1016/j.lindif.2012.01.012

McGeown, S. P., & Medford, E. (2014). Using Method of Instruction to Predict the Skills Supporting Initial Reading Development: Insight from a Synthetic Phonics Approach. *Reading and Writing: An Interdisciplinary Journal, 27*(3), 591-608. doi:10.1007/s11145-013-9460-5

McKone, E., Aimola Davies, A., Fernando, D., Aalders, R., Leung, H., Wickramariyaratne, T., & Platow, M. J. (2010). Asia has the global advantage: Race and visual attention. *Vision Research, 50*(16), 1540-1549. doi:10.1016/j.visres.2010.05.010

Melby-Lervåg, M., Lyster, S.-A. H., & Hulme, C. (2012). Phonological Skills and Their Role in Learning to Read: A Meta-Analytic Review. *Psychological Bulletin, 138*(2), 322-352. doi:10.1037/a0026744

Moll, K., Ramus, F., Bartling, J., Bruder, J., Kunze, S., Neuhoff, N., . . . Landerl, K. (2014). Cognitive mechanisms underlying reading and spelling development in five European orthographies. *Learning and Instruction, 29*, 65-77. doi:10.1016/j.learninstruc.2013.09.003

Morgan, S. F., & Wheelock, J. (1992). Digit Symbol and Symbol Digit Modalities Tests: Are They Directly Interchangeable? *Neuropsychology, 6*(4), 327-330. doi:10.1037/0894-4105.6.4.327

Muter, V., Hulme, C., Snowling, M. J., & Stevenson, J. (2004). Phonemes, Rimes, Vocabulary, and Grammatical Skills as Foundations of Early Reading Development: Evidence From a Longitudinal Study. *Developmental Psychology, 40*(5), 665-681. doi:10.1037/0012-1649.40.5.665

National Autistic Society, (2018, July). About Autism. Retrieved from URL https://www.autism.org.uk/about.aspx

Nelson, J. M., Lindstrom, J. H., Lindstrom, W., & Denis, D. (2012). The Structure of Phonological Processing and Its Relationship to Basic Reading. *Exceptionality, 20*(3), 179-196. doi:10.1080/09362835.2012.694612

NFER Nelson. (1992). Group Reading Test II (response form and manual). London: NFER Nelson.

Neubauer, A. C., Riemann, R., Mayer, R., & Angleitner, A. (1997). Intelligence and reaction times in the Hick, Sternberg and Posner paradigms. *Personality and Individual Differences, 22*(6), 885-894. doi:10.1016/S0191-8869(97)00003-2

NSPCC, (2018, 25th May). Young people turn to Childline over exam stress. Retrieved from URL https://www.nspcc.org.uk/what-we-do/news-opinion/exam-stress-pressure-childline/

Oberauer, K. (2009). Design for a Working Memory.

Oberauer, K., Farrell, S., Jarrold, C., & Lewandowsky, S. (2016). What Limits Working Memory Capacity? *Psychological Bulletin*. doi:10.1037/bul0000046

Oberauer, K., Suss, H. M., Schulze, R., Wilhelm, O., & Wittmann, W. W. (2000). Working memory capacity - facets of a cognitive ability construct. *Personality and Individual Differences, 29*(6), 1017-1045. doi:10.1016/s0191-8869(99)00251-2

Pauc, R., (2005) Comorbidity of dyslexia, dyspraxia, attention deficit disorder (ADD), attention deficit hyperactive disorder (ADHD), obsessive compulsive disorder (OCD) and Tourette's syndrome in children: A prospective epidemiological study *Clinical Chiropractic Volume 8, Issue 4,* December 2005, Pages 189-198

Paul, S.-A. S., & Clarke, P. J. (2016). A systematic review of reading interventions for secondary school students. *International Journal of Educational Research, 79*, 116-127. doi:10.1016/j.ijer.2016.05.011

Peng, P., Namkung, J., Barnes, M., & Sun, C. (2015). A Meta-Analysis of Mathematics and Working Memory: Moderating Effects of Working Memory Domain, Type of Mathematics Skill, and Sample Characteristics. *Journal of Educational Psychology*. doi:10.1037/edu0000079

Pham, A. V., & Hasson, R. M. (2014). Verbal and Visuospatial Working Memory as Predictors of Children's Reading Ability. *Archives of Clinical Neuropsychology, 29*(5), 467-477. doi:10.1093/arclin/acu024

Poirier, M., Martin, J. S., Gaigg, S. B., & Bowler, D. M. (2011). Short-Term Memory in Autism Spectrum Disorder. *Journal of Abnormal Psychology, 120*(1), 247-252. doi:10.1037/a0022298

Powell, D., Stainthorp, R., Stuart, M., Garwood, H., & Quinlan, P. (2007). An Experimental Comparison between Rival Theories of Rapid Automatized Naming Performance and Its Relationship to Reading. *Journal of Experimental Child Psychology, 98*(1), 46-68. doi:10.1016/j.jecp.2007.04.003

Prabhavathi, K., Hemamalini, R. V., Kumar, T. G., Amalraj, C., Maruthy, K. N., & Saravanan, A. (2017). A correlational study of visual and auditory reaction time with their academic performance among the first year medical students. *National Journal of Physiology, Pharmacy and Pharmacology, 7*(4), 371-374. doi:10.5455/njppp.2017.7.1131828112016

R, S. (2007). Deconstructing Rapid Automatized naming: component processes and the prediction of reading difficulties. In.

Re, A. M., Mirandola, C., Esposito, S. S., & Capodieci, A. (2014). Spelling errors among children with ADHD symptoms: The role of working memory. *Research in Developmental Disabilities, 35*(9), 2199-2204. doi:10.1016/j.ridd.2014.05.010

Reimers, S., & Maylor, E. A. (2006). Gender Effects on Reaction Time Variability and Trial-to-Trial Performance: Reply to Deary and Der (2005). *Aging, Neuropsychology, and Cognition, 13*(3-4), 479-489. doi:10.1080/138255890969375

Reynolds, C.R. & Voress, J.K., (2007). *Test of Memory and Learning (2nd Ed).* Austin, Texas: Pro-ed

Roberts, W., & Norwich, B. (2010). Using Precision Teaching to Enhance the Word Reading Skills and Academic Self-Concept of Secondary School Students: A Role for Professional Educational Psychologists. *Educational Psychology in Practice, 26*(3), 279-298. doi:10.1080/02667363.2010.495215

Roivainen, E. (2011). Gender Differences in Processing Speed: A Review of Recent Research. *Learning and Individual Differences, 21*(2), 145-149. doi:10.1016/j.lindif.2010.11.021

Rose, J. (2006, March). Independent review of the teaching of early reading. Retrieved from URL http://dera.ioe.ac.uk/5551/2/report.pdf

Rose, J. (2009, June). Identifying and Teaching Children and Young People with Dyslexia and Literacy Difficulties. Retrieved from URL http://www.thedyslexia-spldtrust.org.uk/media/downloads/inline/the-rose-report.1294933674.pdf

Sacre L. Masterson, M. (2000) *Single Word Spelling Test (NFER),* London: GL assessment

Saddler, B., Behforooz, B., & Asaro, K. (2008). The Effects of Sentence-Combining Instruction on the Writing of Fourth-Grade Students With Writing Difficulties. *The Journal of Special Education*, *42*(2), 79-90. doi:10.1177/0022466907310371

Safford, K. (2016). Teaching Grammar and Testing Grammar in the English Primary School: The Impact on Teachers and Their Teaching of the Grammar Element of the Statutory Test in Spelling, Punctuation and Grammar (SPaG). *Changing English: Studies in Culture and Education, 23*(1), 3-21. doi:10.1080/1358684X.2015.1133766

Savage, R., & Frederickson, N. (2005). Evidence of a Highly Specific Relationship between Rapid Automatic Naming of Digits and Text-Reading Speed. *Brain and Language, 93*(2), 152-159. doi:10.1016/j.bandl.2004.09.005

Savage, R., Pillay, V., & Melidona, S. (2008). Rapid Serial Naming Is a Unique Predictor of Spelling in Children. *Journal of Learning Disabilities, 41*(3), 235-250. doi:10.1177/0022219408315814

Sermier Dessemontet, R., & de Chambrier, A.-F. (2015). The role of phonological awareness and letter-sound knowledge in the reading development of children with intellectual disabilities. *Research in Developmental Disabilities, 41-42*, 1-12. doi:10.1016/j.ridd.2015.04.001

Shanahan, M. A., Pennington, B. F., Yerys, B. E., Scott, A., Boada, R., Willcutt, E. G., . . . DeFries, J. C. (2006). Processing Speed Deficits in Attention Deficit/Hyperactivity Disorder and Reading Disability. *Journal of Abnormal Child Psychology, 34*(5), 584-601. doi:10.1007/s10802-006-9037-8

Shapiro, S. S., & Wilk, M. B. (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika, 52*(3/4), 591-611. doi:10.2307/2333709

Shipstead, Z., Harrison, T. L., & Engle, R. W. (2016). Working Memory Capacity and Fluid Intelligence: Maintenance and Disengagement. *Perspectives on Psychological Science, 11*(6), 771-799. doi:10.1177/1745691616650647

Shitova, N., Roelofs, A. P. A., Schriefers, H. J., Bastiaansen, M. C. M., & Schoffelen, J. M. (2016). Using brain potentials to functionally localise Stroop-like effects in colour and picture naming: Perceptual encoding versus word planning. *PLoS One, 11*, urn:issn:1932-6203.

Siegel, L. S. (1993). PHONOLOGICAL PROCESSING DEFICITS AS THE BASIS OF A READING-DISABILITY. *Developmental Review, 13*(3), 246-257. doi:10.1006/drev.1993.1011

Smith, A., (2010). *Symbol Digit Modalities Test (11th Ed.)* Los Angeles, CA: Western Psychological Services.

Smith, J. (2017). Discursive Dancing: Traditionalism and Social Realism in the 2013 English History Curriculum Wars. *British Journal of Educational Studies, 65*(3), 307-329. doi:10.1080/00071005.2017.1279274

Smith, M., Jones, M. P., Dotson, M. M., & Wolinsky, F. D. (2018). Speed-of-Processing Training in Assisted and Independent Living: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*. doi:10.1111/jgs.15423

Snowling, M. J., & Hulme, C. (2011). Evidence-based interventions for reading and language difficulties: Creating a virtuous circle. *British Journal of Educational Psychology, 81*(1), 1-23. doi:10.1111/j.2044-8279.2010.02014.x

Snowling, M. J., & Melby-Lervåg, M. (2016). Oral Language Deficits in Familial Dyslexia: A Meta- Analysis and Review. *Psychological Bulletin*. doi:10.1037/bul0000037

Snowling, M. J., Muter, V., & Carroll, J. (2007). Children at Family Risk of Dyslexia: A Follow-up in Early Adolescence. *Journal of Child Psychology and Psychiatry, 48*(6), 609-618. doi:10.1111/j.1469-7610.2006.01725.x

SpLD Assessment Standards Committee (2016, March). SpLD assessment tools. Retrieved from URL http://www.sasc.org.uk/SASC_Default.aspx?id=2

St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving Children's Working Memory and Classroom Performance. Educational Psychology, 30(2), 203-219. doi:10.1080/01443410903509259

Stacey, G. (2015, 18th March). Retrieved from URL https://ofqual.blog.gov.uk/2015/03/18/gcse-english-literature-learning-and-understanding-not-memory/

Stanovich, K.E. (2000) *Progress in understanding reading: scientific foundations and new frontiers.* New York: Guildford Press

Studer-Luethi, B., Bauer, C., & Perrig, W. (2016). Working memory training in children: Effectiveness depends on temperament (vol 44, pg 171, 2016). *Mem. Cogn., 44*(2), 187-187. doi:10.3758/s13421-016-0587-x

Suggate, S., Pufke, E., & Stoeger, H. (2016). The effect of fine and grapho-motor skill demands on preschoolers' decoding skill. *Journal of Experimental Child Psychology, 141*, 34-48. doi:10.1016/j.jecp.2015.07.012

Sumner, E., Pratt, M. L., & Hill, E. L. (2016). Examining the cognitive profile of children with Developmental Coordination Disorder. *Research in Developmental Disabilities, 56*, 10-17. doi:10.1016/j.ridd.2016.05.012

Swanson, H. L. (2011). Dynamic Testing, Working Memory, and Reading Comprehension Growth in Children with Reading Disabilities. *Journal of Learning Disabilities, 44*(4), 358-371. doi:10.1177/0022219411407866

Swanson, H. L., & Berninger, V. W. (1996). Individual Differences in Children's Working Memory and Writing Skill. *Journal of Experimental Child Psychology, 63*(2), 358-385. doi:10.1006/jecp.1996.0054

Swanson, H. L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology, 96*(4), 249-283. doi:10.1016/j.jecp.2006.12.004

Taskin, C. (2016). The Visual and Auditory Reaction Time of Adolescents with Respect to Their Academic Achievements. *Journal of Education and Training Studies, 4*(3), 202-207. doi:10.11114/jets.v4i3.1374

Tattersall, P. J., Nelson, N. W., & Tyler, A. A. (2015). Associations among nonword repetition and phonemic and vocabulary awareness: Implications for intervention. *Child Language Teaching and Therapy, 31*(2), 159-171. doi:10.1177/0265659014554719

Terry, H. (2012). History in Schools and the Problem of "The Nation". *Education Sciences, 2*(4), 276-289. doi:10.3390/educsci2040276

Toffalini, E., Marsura, M., Garcia, R. B., & Cornoldi, C. (2018). A Cross-Modal Working Memory Binding Span Deficit in Reading Disability. *Journal of learning disabilities*, 22219418786691. doi:10.1177/0022219418786691

Torgerson, T.J., Brooks, G., & Hall, (2006). A systematic Review of the Research Literature on the Use of Phonics in the Teaching of Reading and Spelling. Retrieved from URL http://dera.ioe.ac.uk/14791/1/RR711_.pdf

Torgesen, J., Wagner, R. and Rashotte, C. (2012) *Test of Word Reading Efficiency, (2nd Ed) (TOWRE 2),* Austin, Texas: Pro-ed.

Tourva, A., Spanoudis, G., & Demetriou, A. (2016). Cognitive correlates of developing intelligence: The contribution of working memory, processing speed and attention. *Intelligence, 54,* 136-146. doi:10.1016/j.intell.2015.12.001

Tukey, J. W. (1977). *Exploratory data analysis / John W. Tukey*. Reading [Mass.] ; London: Reading Mass. ; London : Addison-Wesley.

Vander Stappen, C., & Reybroeck, M. V. (2018). Phonological Awareness and Rapid Automatized Naming Are Independent Phonological Competencies With Specific Impacts on Word Reading and Spelling: An Intervention Study. *Frontiers in psychology, 9*, 320. doi:10.3389/fpsyg.2018.00320

Vellutino, F. R., Tunmer, W. E., Jaccard, J. J., & Chen, R. (2007). Components of Reading Ability: Multivariate Evidence for a Convergent Skills Model of Reading Development. *Scientific Studies of Reading, 11*(1), 3-32. doi:10.1207/s1532799xssr1101_2

Vernon, P. A. (1986). The g-loading of intelligence tests and their relationship with reaction times: A comment on Ruchalla et al. *Intelligence, 10*(2), 93-100. doi:10.1016/0160-2896(86)90009-7

Vernon, P. A., Nador, S., & Kantor, L. (1985). Reaction times and speed-of-processing: Their relationship to timed and untimed measures of intelligence. *Intelligence, 9*(4), 357-374. doi:10.1016/0160-2896(85)90020-0

Wagner, R. K., & Torgesen, J. K. (1987). THE NATURE OF PHONOLOGICAL PROCESSING AND ITS CAUSAL ROLE IN THE ACQUISITION OF READING-SKILLS. *Psychological Bulletin, 101*(2), 192-212. doi:10.1037//0033-2909.101.2.192

Wagner, R.k., Torgesen, J.K., Rashotte, C.A. & Pearson, N.A., (2013). *Comprehensive Test of Phonological Processing (2nd Ed).* Austin, Texas: Pro-ed

Webster, R. E., & et al. (1996). Memory Modality Differences in Children with Attention Deficit Hyperactive Disorder with and without Learning Disabilities. *Psychology in the Schools, 33*(3), 193-201. doi:10.1002/(SICI)1520-6807(199607)33:3<193::AID-PITS2>3.0.CO;2-R

Witt, M. (2011). School based working memory training: Preliminary finding of improvement in children's mathematical performance. *Advances in cognitive psychology, 7*, 7. doi:10.2478/v10053-008-0083-3

Wolf, M., Barzillai, M., Gottwald, S., Miller, L., Spencer, K., Norton, E., . . . Morris, R. (2009). The RAVE-O Intervention: Connecting Neuroscience to the Classroom. *Mind, Brain, and Education, 3*(2), 84-93. doi:10.1111/j.1751-228X.2009.01058.x

Wolf, M., & Bowers, P. G. (1999). The Double- Deficit Hypothesis for the Developmental Dyslexias. *Journal of Educational Psychology, 91*(3), 415-438. doi:10.1037/0022-0663.91.3.415

Wyse, D., & Goswami, U. (2008). Synthetic phonics and the teaching of reading. *British Educational Research Journal, 34*(6), 691-710. doi:10.1080/01411920802268912

Ziegler, J. C., Bertrand, D., Tóth, D., Csépe, V., Reis, A., Faísca, L., . . . Blomert, L. (2010). Orthographic Depth and Its Impact on Universal Predictors of Reading: A Cross-Language Investigation. *Psychological Science, 21*(4), 551-559. doi:10.1177/0956797610363406